CALTRANS CLIMATE CHANGE

VULNERABILITY ASSESSMENT SUMMARY REPORT

DISTRICT 7

2019

Caltrans

wsp

RESILIENCE: THE ABILITY TO PREPARE AND PLAN FOR, ABSORB, RECOVER FROM, OR MORE SUCCESSFULLY ADAPT TO ADVERSE EVENTS.[1]

This Summary Report and its associated Technical Report describe climate change effects in District 7. This document provides a high-level review of potential climate impacts to the District's portion of the State Highway System, while the Technical Report presents detail on the technical processes used to identify these impacts. Similar reports are being prepared for each of Caltrans' 12 districts.

A database containing climate stressor geospatial data indicating changes in climate over time (e.g. temperature rise and increased likelihood of wildfires) was developed as part of this study. The maps included in this report and the Technical Report use data from this database, and it is expected to be a valuable resource for ongoing Caltrans resiliency planning efforts and coordination with stakeholders. Caltrans will use this data to evaluate the vulnerability of the State Highway System and other Caltrans assets, and inform future decision-making.

In the California and the western U.S., these general climate trends are expected[2]:

- More severe droughts, less snowpack, and changes in water availability
- Rising sea levels, more severe storm impacts, and coastal erosion
- Increased temperatures and more frequent, longer heat waves
- Longer and more severe wildfire seasons

1 - American Association of State Highway and Transportation Officials (AASHTO resilience definition)

2 - "Global Warming in the Western United States," Union of Concerned Scientists, http://www.ucsusa.org/global_warming/regional_information/ca-and-western-states.html#.WMwOFm_yvIU

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OVERVIEW OF METHODOLOGY

The data analysis presented in this report is largely based on global climate data compiled by the Intergovernmental Panel on Climate Change (IPCC) and California research institutions like the Scripps Institution of Oceanography. This data was developed to estimate the Earth's natural response to increasing carbon emissions. Research institutions represent these physical processes through Global Climate Models (GCMs). Thirty-two different GCMs have been downscaled to a regional level and refined so they can be used specifically for California. Of those, ten were identified by California state agencies to be the most applicable to California. This analysis used all ten of these representative GCMs, but only the median model is reported in this Summary Report (and the associated Technical Report) due to space limitations.

The IPCC represents future emissions conditions through a set of representative concentration pathways (RCPs) that reflect four scenarios for greenhouse gas (GHG) emission concentrations under varying global economic forces and government policies. The four scenarios are RCP 2.6, RCP 4.5, RCP 6.0, and RCP 8.5. This analysis considered RCP 4.5, which assumes that carbon emissions will peak by mid-century, and RCP 8.5, which assumes a continuation of current emission trends until end of century. This Summary Report presents only results from the RCP 8.5 analysis—the RCP 4.5 analysis is summarized in the associated Technical Report, and the aforementioned geospatial database.

EVACUATION PLANNING

Among the things that Caltrans must consider when planning for climate change is the role of the State Highway System (SHS) when disaster strikes. The SHS is the backbone of most county-level evacuation plans and often provides the only high-capacity evacuation routes from rural communities. In addition, state highways also serve as the main access routes for emergency responders, and may serve as a physical line of defense (a firebreak, an embankment against floodwaters, etc.). As climate-related disasters become more frequent and more severe, this aspect of SHS usage will assume a greater importance that may need to be reflected in design. The upcoming studies of climate change adaptation measures will take these factors into account when identifying measures appropriate to each situation.

BACKGROUND AND APPROACH

Caltrans is making a concerted effort to identify the potential climate change vulnerabilities of the State Highway System.[3] The information presented in this report is the latest phase of this effort. It identifies portions of the State Highway System that could be vulnerable to different climate stressors and Caltrans processes that may need to change as a result.

This study involved applying available climate data to refine the understanding of potential cliamte risks, and Caltrans coordinated with various state and federal agencies and academic institutions on how to best use the most recent data. Discussions with professionals from various engineering disciplines helped identify the measures presented in this report.

The information in this Summary Report outlines the potential vulnerabilities to Caltrans' District 7 portion of the State Highway System and illustrates the types of climate stressors that may affect how highways are planned, designed, built, operated, and maintained. The intent of the current study is to add clarity regarding climate change in the region served by District 7, a subject with many unknowns, and begin to define a subset of assets on the State Highway System on which to focus future efforts. Thus, this report does not identify projects to be implemented, nor does it present the cost associated with such projects. These items will be addressed in future studies.

3 - Caltrans is responsible for other assets, including those related to rail and mass transit, which are not the focus of this specific assessment.

DISTRICT 7 MANAGES SOME OF THE MOST HEAVILY TRAFFICKED ROADS IN CALIFORNIA AND IS DEDICATED TO IMPROVING ITS AGING HIGHWAY INFRASTRUCTURE.

DISTRICT 7 CHARACTERISTICS

District 7 is a socially and geologically diverse district spanning roughly 7,000 square miles in Southern California. District 7 includes Los Angeles and Ventura Counties, which have populations of 10.1 million and 850,000 people respectively. The climate is generally dry and mild but it can vary due to the area's topological diversity which includes mountain ranges, low-lying coastal plains, beaches, lakes, deserts, and large urban areas. Major District 7 features include the Santa Monica and San Gabriel mountain ranges, the Los Padres and Angeles National Forests, and the cities of Los Angeles, Long Beach, and Oxnard. The district also includes a portion of the Mojave Desert, the Tehachapi Mountains, and two Channel Islands, San Clemente and Santa Catalina.

The district has the second largest workforce of all 12 Caltrans districts and employs nearly 2,500 people. District 7 Traffic Operations and Maintenance manage 1,173 miles of state highway in Los Angeles County and 300 miles in Ventura County. These are some of the most heavily trafficked roads in California, with average daily usage miles of roughly 111 million vehicle miles. District 7 is actively maintaining the heavily used infrastructure in both counties, and working to reduce congestion in a variety of ways, including high-occupancy vehicle (HOV) lanes. The district manages 550 HOV lane-miles in Los Angeles County and 7.5 HOV lane-miles in Ventura County, with more under construction. Senate Bill 1 is expected to fund $2.6 billion in new projects for Los Angeles and Ventura Counties, with the funds dedicated to improving infrastructure, reducing congestion, and bolstering climate resiliency.

KEY STATE POLICIES ON CLIMATE CHANGE

There are multiple California state climate change adaptation policies that apply to Caltrans decision-making. Some of the major policies relevant to Caltrans include:

> **Executive Order (EO) B-30-15 – requires the consideration of climate change in all state investment decisions through the use of full life cycle cost accounting, the prioritization of adaptation actions which also mitigate GHGs, the consideration of the state's most vulnerable populations, the prioritization of natural infrastructure solutions, and the use of flexible approaches where possible. The Governor's Office of Planning and Research (OPR) have since released guidance for implementing EO B-30-15 titled Planning and Investing for a Resilient California. (footnote) The document provides high level guidance on how state agencies should consider and plan for future conditions. Caltrans supported the development of this guidance by serving on a Technical Advisory Group convened by OPR.[4]**
>
> **Assembly Bill 1482 – requires all state agencies and departments to prepare for climate change impacts with efforts including: continued collection of climate data, considering climate in state investments, and the promotion of reliable transportation strategies.[5]**
>
> **Assembly Bill 2800 – requires state agencies to take into account potential climate impacts during planning, design, building, operations, maintenance, and investments in infrastructure. It also requires the formation of a Climate-Safe Infrastructure Working Group consisting of engineers with relevant experience from multiple state agencies, including Caltrans.[6] The Working Group has since completed Paying it Forward: The Path Toward Climate-Safe Infrastructure in California, which recommends strategies for legislators, engineers, architects, scientists, consultants, and other key stakeholders to develop climate ready, resilient infrastructure for California.[7]**

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4 - California Governor's Office of Planning and Research, "Planning and Investing for a Resilient California," March 13, 2018, http://opr.ca.gov/planning/icarp/resilient-ca.html

5 - "Assembly Bill No. 1482," California Legislative Information, October 8, 2015, https://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201520160AB1482

6 - "Assembly Bill No. 2800," California Legislative Information, September 24, 2016, http://leginfo.legislature.ca.gov/faces/billNavClient.xhtml?bill_id=201520160AB2800

7 - Climate-Safe Infrastructure Working Group, Paying it Forward: The Path Toward Climate-Safe Infrastructure in California, September 2018, http://resources.ca.gov/climate/climate-safe-infrastructure-working-group/

RECENT EXTREME EVENTS IN DISTRICT 7

Over the past few years, District 7 has had to repair damage caused by several extreme weather events. These are examples of the challenges that Caltrans District 7 could face more frequently as conditions change. These challenges can be categorized in terms of:

- **Temperature** – Following the drought from 2012 to 2017, trees around the state were weakened and attacked by bark beetle and disease. In 2016, Caltrans District 7 removed 4,800 dead (or dying) trees along State Highway System right-of-way to prevent damages that could be caused by storm, wind, or wildfire events.
- **Precipitation** – Heavy rain events in 2014 caused landslides all along the Pacific Coast Highway (PCH) between Yerba Buena Road and Las Posas Road. In some locations there was six feet of mud and those sections needed to be closed for repair. District 7 removed mud and debris, repaired the highway shoulders, and replaced riprap that had washed away. Flash floods also caused traffic-stopping mudslides in 2015 along Interstate 5 in the Tehachapi Mountains.
- **Wildfire** – 2017 included some of the most destructive and deadly wildfires in California history. From early December 2017 through early January 2018, the Thomas Fire burned 281,893 acres in Districts 5 and 7. Heavy rains after the fire led to devastating mudslides throughout the region, triggering evacuation orders and causing at least 20 fatalities. See pages 22-23 for more on the Thomas Fire.
- **Sea Level Rise and Storm Surge** – While sea level rise has not yet had any major impact to District 7, in 2010, high surf conditions damaged the PCH, including drainage infrastructure and rock slope shore protection. Storm events have also led to erosion, scour, and washouts on the PCH in District 7.


PACIFIC COAST HIGHWAY WAVE RUN-UP DAMAGE, 2014


PACIFIC COAST HIGHWAY SLIDE DAMAGE


PACIFIC COAST HIGHWAY | ONE-WAY EXIDUS FROM WOOLSEY FIRE 2018


PACIFIC COAST HIGHWAY HIGH-SURF DAMAGE, 2010

PACIFIC COAST HIGHWAY FLOODING, 2014


WASHED OUT SLOPE AND EMBANKMENT ON SR-210

VULNERABILITY AND THE STATE HIGHWAY SYSTEM

CALTRANS EFFORTS

For the last ten years, Caltrans has been addressing climate change concerns and has developed guidance for incorporating climate change considerations into project design and other functional Caltrans responsibilities. Activities include:

- Reporting adaptation goals and progress to OPR through the *State Sustainability Roadmaps, Adaptation Chapters.*[8]
- Releasing *Guidance on Incorporating Sea Level Rise* (2011) to advance effective design and programmatic considerations that incorporate sea level rise projections.
- Issuing *Addressing Climate Change Adaptation in Regional Transportation Plans* (2013) which serves as a how-to guide for California Metropolitan Planning Organizations (MPOs) and Regional Transportation Planning Agencies (RTPAs).
- Signing an agreement with the California Coastal Commission and its Integrated Planning Team to ensure effective collaboration between agencies—including planning for sea level rise impacts.[9]

Caltrans' continuing efforts include developing a more thorough understanding of the risks to the state's transportation system and taking the necessary actions to ensure the resiliency of the transportation system for California.

ADDRESSING CONCERNS IN DISTRICT 7

Caltrans District 7's portion of the State Highway System serves critical functions for communities, commerce, and more. Given this importance, understanding the potential impacts of climate change and extreme weather on system performance is key to creating a resilient highway system.

"Vulnerability" is often used to describe the degree to which assets, facilities, and even the entire transportation system, might be disrupted by climate change or other stressors. Caltrans' focuses its approach on the system's vulnerability to extreme weather and climate-related hazards and recognizes the importance of the many Caltrans units necessary to support a resilient state transportation system.

The approach outlined on the following page describes a process consistent with Caltrans practices. It focuses on three issues:

- **Prioritization** – determining how to make effective capital programming decisions to address identified risks (including the consideration of system use and timing of expected exposure).
- **Exposure** – identifying Caltrans assets that may be affected by expected future weather or climate conditions, such as: permanent inundation from sea level rise, temporary flooding from storm surge, or a wide range of damages from wildfire.
- **Consequence** – determining what damage might occur to system assets in terms of loss of use or costs of repair.

Implementing this approach will require the support of a wide range of Caltrans professionals from planning, asset management, operations and maintenance, design, emergency response, and economics. It will also require coordination with environmental and social resource agencies. For this approach to succeed, it will take an agency-wide effort.

ENSURING SYSTEM RESILIENCY

Once system vulnerabilities are identified, Caltrans will begin considering enhanced system resiliency when choosing projects and project designs. In District 7 this primarily requires implementing projects to address sea level rise, storm surge, coastal erosion, and wildfire events.

Some strategies might include:

- Raising roadways, increasing drainage, and installing pumping systems to prevent inundation of highway from sea level rise
- Realigning and siting new roadways to avoid areas affected by sea level rise, storm surge, and coastal erosion.[10]
- Natural infrastructure and living shoreline strategies should be considered where they will be effective (not in areas with high wave action)[11]
- Keeping landscaping "fire-safe" in wildfire risk areas by using fire-resistant plants that are high-moisture, grow close to the ground, and have low sap content [12]

These efforts will require Caltrans to be proactive and invest in the long-term viability of the transportation system.

8 - Governor's Office of Planning and Research, "Tracking Progress Over Time: State Sustainability Roadmaps," October, 2018, http://opr.ca.gov/meetings/tac/2018-10-12/docs/20181012-4_Tracking_Progress_Over_Time.pdf

9 - Integrated Planning Team, "Plan for Improved Agency Partnering: Caltrans and California Coastal Commission," December 21, 2016, http://www.dot.ca.gov/ser/downloads/MOUs/iaccc-improved-agency-partnering-agreement.pdf

10 - Molly Loughney Melius and Margaret R. Caldwell, "California Coastal Armoring Report: Managing Coastal Armoring and Climate Change Adaptation in the 21st Century," Environment and Natural Resources Law & Policy Program Working Paper, (June 2015), https://law.stanford.edu/publications/california-coastal-armoring-report-managing-coastal-armoring-and-climate-change-adaptation-in-the-21st-century/

11 - Ibid.

12 - "Fire-Resistant Landscaping," CalFire, http://www.readyforwildfire.org/Fire-Safe-Landscaping/

THE CALTRANS APPROACH TO VULNERABILITY OUTLINED BELOW WAS DEVELOPED TO HELP GUIDE FUTURE PLANNING AND PROGRAMMING PROCESSES. IT DESCRIBES ACTIONS TO ACHIEVE LONG-TERM HIGHWAY SYSTEM RESILIENCY.

THE APPROACH INCLUDES THE FOLLOWING KEY ELEMENTS:

CONDUCT A VULNERABILITY ASSESSMENT OF ALL CALTRANS ASSETS

INCLUDING EXPECTED TIMING OF IMPACTS

IDENTIFY THE SUBSET OF ASSETS EXPOSED TO EXTREME WEATHER EVENTS AND CLIMATE CHANGE

DETERMINE THE CONSEQUENCE OF IMPACTS ON CALTRANS ASSETS

DAMAGE/LOSS DURATION

PRIORITIZE ACTIONS

BASED ON TIMING AND CONSEQUENCE OF IMPACTS

CURRENT STAGE

EXPOSURE

Define the components and locations of the highway system (roads, bridges, culverts, etc.) that may be exposed to changing conditions caused by the effects of climate change such as sea level rise, storm surge, wildfire, landslides, and more. Key indicators for this measure include the potential timing of expected changes – e.g., what year could you expect these conditions to occur.

CONSEQUENCE

Identify the implications of extreme weather or climate change on Caltrans assets. Key variables include estimates of cost of damage and the length of closure to repair or replace the asset and measures of environmental or social impacts. The consequence of failure from climate change include (among others):

- Sea level rise and storm surge inundating roadways and bridges forcing their closure, which could lead to delays and detours.
- Wildfire primary and secondary effects (debris loads/ landslides) on roadways, bridges and culverts.
- Precipitation changes, and other effects such as changing land use, that combined, could increase the level of runoff and flooding.
- Impacts to the safety of the traveling public from flash flooding, loss of guardrails and signage from wildfires, debris on the roadway from flooding, wildfire, and landslide events, and limited visibility from poor air quality.

PRIORITIZATION

Develop a method to support investment decision-making from among multiple options related to future climate risk, with elements including:

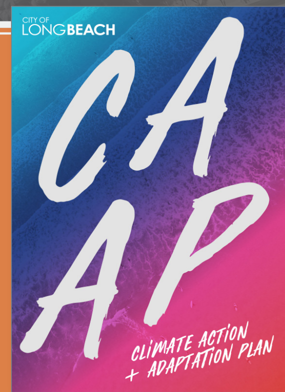
- Timing – how soon can the impacts be expected?
- Impacts – what are the projected costs to repair/replace? What is the likely time of outage? What are the likely impacts on travel/goods movement?
- Safety – who will be directly or indirectly affected? How can impacts to vulnerable populations be avoided? How will worker safety be affected?

BY USING THIS APPROACH, CALTRANS CAN CAPITALIZE ON ITS INTERNAL CAPABILITIES TO IDENTIFY PROJECTS THAT INCREASE STATE HIGHWAY SYSTEM RESILIENCY.

OTHER EFFORTS IN DISTRICT 7 TO ADDRESS CLIMATE CHANGE

Caltrans recognizes that other regional efforts are underway in District 7 to mitigate the effects of climate change. Ongoing coordination with local governments and stakeholders will be critical to ensure that methodologies and adaptation strategies are not redundant with other efforts. Regional coordination will be especially important to combat stressors, such as responding to rising seas, that will affect everyone and require a collective response.

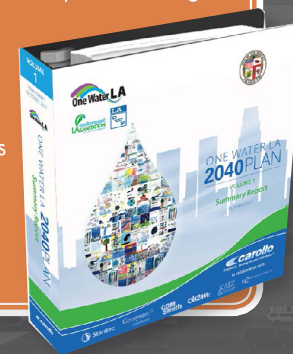
CLIMATE ACTION PLANS



Many cities and counties in District 7 have adopted Climate Action Plans (CAPs) designed to mitigate GHG emissions and reduce the impacts of climate change to their communities. Los Angeles County has adopted a Community CAP (CCAP) to mitigate and limit GHG emissions associated with community activities in unincorporated Los Angeles County. The CCAP addresses emissions from buildings, land use, transportation, water consumption, and waste. The measures and actions outlined in the CCAP will connect the county's existing climate change initiatives and provide a blueprint for a more sustainable future. The CCAP identifies emissions related to community activities, establishes a GHG reduction target consistent with AB 32, and provides a roadmap for successfully implementing the county's GHG reduction measures.[13]

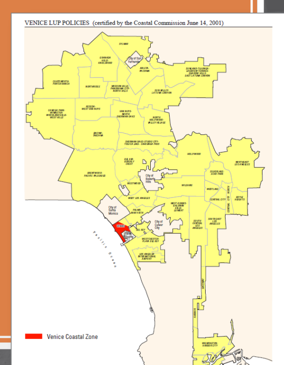
ONE WATER LOS ANGELES PLAN

The City of Los Angeles is developing the One Water LA 2040 Plan, which is focused on increasing local collaboration in water-planning processes. The plan is a roadmap, connecting ideas and people to discover better and more fiscally-responsible water-planning solutions. The plan specifically identifies projects, programs, and policies that will yield sustainable, long-term water supplies for Los Angeles and promote greater resiliency to drought conditions and climate change.[14]



LOCAL COASTAL PROGRAMS

The California Coastal Commission is working with Ventura County and several cities in District 7, including Oxnard, Santa Monica, Hermosa Beach, and the City of Los Angeles to update their Local Coastal Programs (LCPs) to account for climate change impacts—especially from sea level rise. These LCPs are tools used by local governments to plan the development and protection of the coastal zone. Once updated, they will also include strategies to reduce infrastructure impacts from sea level rise, storm surge, and other climate stressors.



LOS ANGELES REGIONAL COLLABORATIVE FOR CLIMATE ADAPTATION

The Los Angeles Regional Collaborative (LARC) is a founding member of the Alliance of Regional Collaboratives for Climate Adaptation (ARCCA), which is a network of regional collaboratives from across California. ARCCA's collaboratives coordinate and support climate adaptation efforts in their own regions to enhance public health, protect natural systems, build economies, and improve local quality of life.[15]

LARC

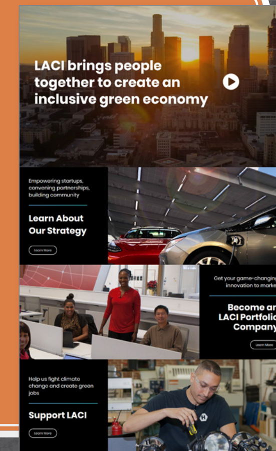
13 - Los Angeles County Department of Regional Planning, "Community Climate Action Plan," accessed April 29, 2019, http://planning.lacounty.gov/CCAP
14 - "One Water LA," Los Angeles County, accessed April 29, 2019, LINK
15 - "Projects & Initiatives," Los Angeles Regional Collaborative for Climate Action and Sustainability, accessed April 29, 2019, http://www.laregionalcollaborative.com/projects/

CLIMATE RESOLVE

Climate Resolve is a Los Angeles-based nonprofit organization focused on local solutions for global climate change. The organization works to make California more sustainable now and in the future by promoting reduced climate pollution and proactively preparing for climate impacts. To achieve their mission, Climate Resolve works to reduce GHG emissions and build collaborative partnerships to implement regional climate initiatives. Climate Resolve helps keep cities resilient in the face of climate change by disseminating information to make local climate impacts relatable and solutions actionable.[16]

LOS ANGELES CLEANTECH INCUBATOR (LACI)

The Los Angeles Cleantech Incubator (LACI) supports the development and success of cleantech start-ups in Los Angeles County. In regards to transportation, LACI focuses on bolstering start-ups that are focused on accelerating the transition toward zero emission vehicles to reduce greenhouse gas emissions and minimize localized air pollution. LACI has developed a report about this initiative, titled "Zero Emissions Roadmap."[17]



THE SOUTHERN CALIFORNIA ASSOCIATION OF GOVERNMENTS (SCAG)

The Southern California Association of Governments is made up of six counties, including Ventura and Los Angeles from District 7. The agency develops the Regional Transportation Plan and associated Sustainable Communities Strategy for the area. SCAG is currently working on a regional climate adaptation framework to incorporate existing state adaptation policy guidance with local and regional land-use planning. The project will provide local jurisdictions with toolkits for project implementation and outline a regional framework and strategy for adaptation.[18]

SCAG™ INNOVATING FOR A BETTER TOMORROW

LOS ANGELES METRO CLIMATE PROGRAM

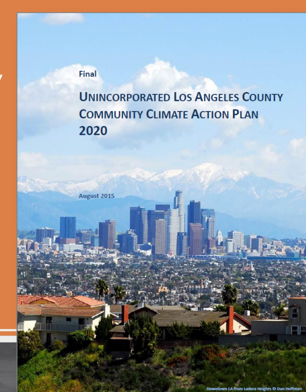
LA Metro's Climate Program addresses climate change through two pillars: GHG mitigation and resiliency planning. To address GHG emission reductions, LA Metro conducts accounting of annual emissions and sets targets for further reduction. They also operate the largest alternatively fueled fleet in the nation by using buses that run on biomethane. The resiliency component seeks to address how the Metro system can respond to shocks, such as extreme weather events. The program's guiding document is their 2012 Climate Action and Adaptation Plan, for which an update is expected in 2019.[19]

Metro™

LOS ANGELES COUNTY

The Los Angeles County Department of Regional Planning developed the Community Climate Action Plan (CCAP) that was adopted in 2015. The CCAP set a goal for the county to reduce GHGs generated from community activities by 11% below 2010 levels by the year 2020. The CCAP comprehensively addresses emissions produced from land use and transportation, water consumption, waste generation and building energy.[20]

In addition to this effort, the Chief Sustainability Office of Los Angeles County is currently developing a countywide sustainability plan title "Our County." The plan aims to provide a holistic view of sustainability issues and will address a range of topics, including climate change and transportation.[21]



16 - "About Us," Climate Resolve, accessed April 29, 2019, http://climateresolve.org/2018/about-us/
17 - "LA Incubator," LACI, accessed October 3, 2018, https://laincubator.org/
18 - "Transit: Adaptation and Resilience Planning for Providers of Public Transportation," SCAG, accessed April 29, 2019, http://www.scag.ca.gov/programs/Pages/Adaptation-and-Resilience-Planning.aspx
19 - "Climate Response," LA Metro, accessed October 3, 2018, https://www.metro.net/projects/sustainability/climate-program/
20 - County of Los Angeles, "Unincorporated Los Angeles County Community Climate Action Plan," August, 2015, http://planning.lacounty.gov/assets/upl/project/ccap_final-august2015.pdf
21 - "Our County," accessed April 29, 2019 County of Los Angeles, http://sustainabilityplan.lacounty.gov/#

PHASES FOR ACHIEVING RESILIENCY

California has been a national leader in responding to extreme climatic conditions, particularly in regards to Executive Order B-30-15. Successful adaptation to climate change includes a structured approach that anticipates likely disruptions and institutes effective changes in agency operating procedures. The steps shown below outline the approach to achieve resiliency at Caltrans and show how work performed on this this study fits within that framework.

PREDICT CLIMATE CHANGE EFFECTS:
Climate change projections suggest that temperatures will be warmer, that precipitation patterns will change, sea levels will rise, and that a combination of these stressors could lead to other types of disruptions, such as those associated with wildfires.

UNDERSTAND POSSIBLE TRANSPORTATION IMPACTS:
Higher precipitation levels could cause more flooding and landslides. Sea level rise and/or storm surge could inundate or damage low-lying coastal roads and bridges. Higher temperatures could affect state highway maintenance and their risk due to wildfires. Understanding these potential impacts provides an impetus to study ways to enhance the resiliency of the State Highway System.

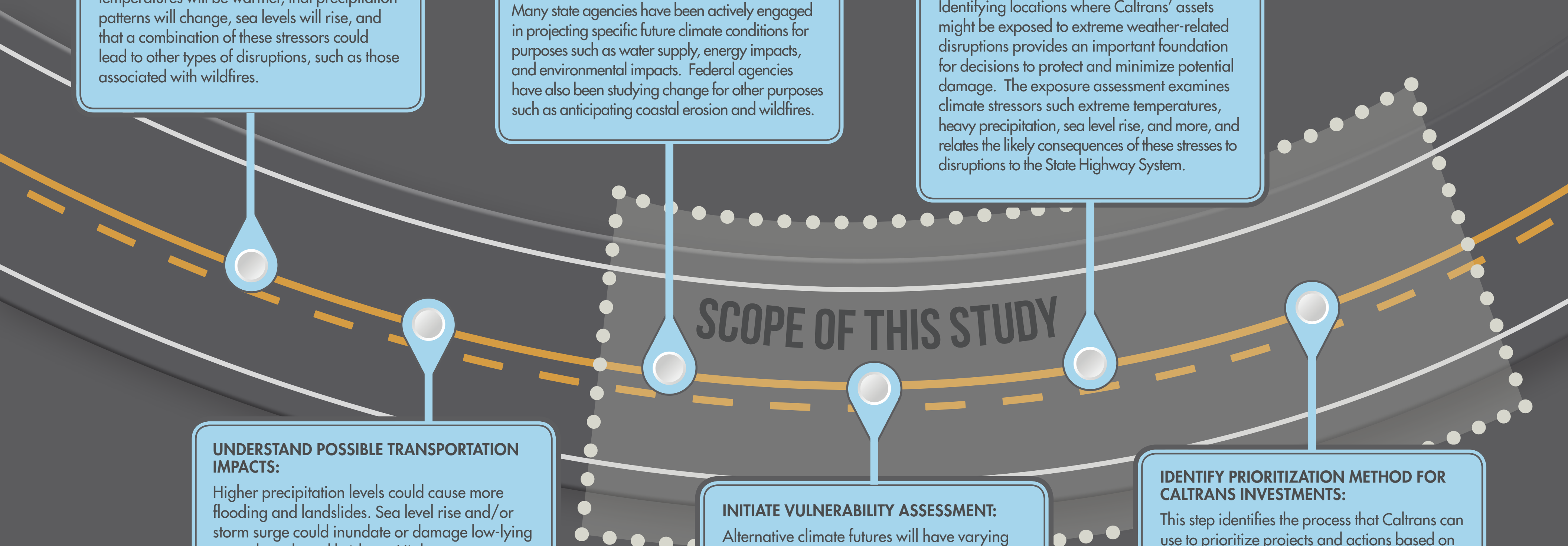
COORDINATE WITH FEDERAL/STATE RESOURCE AGENCIES ON APPLICABLE CLIMATE DATA:
Many state agencies have been actively engaged in projecting specific future climate conditions for purposes such as water supply, energy impacts, and environmental impacts. Federal agencies have also been studying change for other purposes such as anticipating coastal erosion and wildfires.

INITIATE VULNERABILITY ASSESSMENT:
Alternative climate futures will have varying impacts on the State Highway System. This step includes an examination of the range of climatic stressors and where, due to terrain or climatic region, portions of the State Highway System might be vulnerable to future disruptions.

IDENTIFY EXPOSURE OF CALTRANS HIGHWAYS TO POSSIBLE CLIMATE CHANGE DISRUPTIONS:
Identifying locations where Caltrans' assets might be exposed to extreme weather-related disruptions provides an important foundation for decisions to protect and minimize potential damage. The exposure assessment examines climate stressors such extreme temperatures, heavy precipitation, sea level rise, and more, and relates the likely consequences of these stresses to disruptions to the State Highway System.

IDENTIFY PRIORITIZATION METHOD FOR CALTRANS INVESTMENTS:
This step identifies the process that Caltrans can use to prioritize projects and actions based on their likely system resiliency benefits, through reduced impacts to system users.

This process will focus on resiliency benefits and the timeframe of potential impacts, and could guide the timing of investment actions.



DEVELOP ACTION PLANS FOR EACH CALTRANS FUNCTIONAL AREA

(including planning and modal programs, project delivery, and maintenance & operations):

Each of the functional areas in Caltrans would develop an Action Plan for furthering resiliency-oriented projects and processes in their area of responsibility. These action plans would define specific action steps, the estimated benefits to the State of California related to these steps, a timeline and staff responsibility.

INCORPORATE RESILIENCY PRACTICES THROUGHOUT CALTRANS:

Each Caltrans functional area will be responsible for incorporating those actions that are outlined in their Action Plan, while reporting progress regularly to agency leadership.

DEVELOP AND IMPLEMENT PILOT STUDIES FOR PLANNING AND PROJECT DEVELOPMENT AND MORE:

Pilot studies could be developed specific to each functional area and provide a "typical" experience for that function. Each pilot study would be assessed from the perspective of lessons learned and how the experience can guide project implementation, and actions similar to those in the pilot studies.

PRIORITIZE A SET OF PROJECTS/ACTIONS FOR ENGINEERING ASSESSMENTS:

The prioritization method will help Caltrans identify those projects and actions with the most benefit in terms of enhancing system resiliency. Prioritization could focus on those projects with primary benefits related to system resiliency, or on other projects with benefits that could go beyond resiliency.

ADVANCE PROJECTS/ACTIONS TO APPROPRIATE INVESTMENT PROGRAMS:

Implementing resiliency-oriented actions and projects will require funding and other agency resources. This step advances those actions, and projects prioritized above, into the final decisions relating to funding and agency support, whether it is the capital program or other budget programs.

MONITOR EFFECTS OF PROJECTS/ACTIONS AND MODIFY GUIDANCE AS APPROPRIATE:

This step is the traditional "feedback" into the decisions that started a particular initiative. In this case, the monitoring of the effects of resiliency-oriented projects and actions adopted by Caltrans is needed to assess if resiliency efforts have been effective over time. This monitoring is a long-term effort, and one that will vary by functional responsibility within Caltrans.

TEMPERATURE

TGuidance from the US National Climate Assessment states that the "number of extremely hot days is projected to continue to increase over much of the United States, especially by late century. Summer temperatures are projected to continue rising, and a reduction of soil moisture, which exacerbates heat waves, is projected for much of the western and central US in summer."[22] Due to California's size, and its many highly varied climate zones, temperatures are expected to rise in varying degrees across the state.

The figure on the following page illustrates the average maximum temperature change over seven consecutive days (an important element for determining the best pavement mix for long-term performance) for three time periods, compared to a historical backcasted period from 1975 to 2004. US studies have generally found that increasing temperatures could impact the transportation system in several ways, including:

DESIGN

- Ground conditions and water saturation levels can affect foundations and retaining walls.
- High temperatures over long periods of time can deform materials (including by pavement heave and track buckling). Pavement designs must consider high temperatures to mitigate future deterioration.

OPERATIONS AND MAINTENANCE

- High temperatures for extended periods could increase the need for protected transit facilities along roadways.
- Extreme heat events could affect worker health and safety, especially for those working outdoors for long hours.
- Vegetation and right-of-way landscaping must be able to survive longer periods of high temperatures.
- Higher temperatures could deteriorate bridge joint seals due to expansion—this could accelerate replacement schedules and even affect bridge superstructure.

TEMPERATURE CHANGE IN DISTRICT 7

The average maximum temperature over seven days is expected to increase by up to 3.9° around 2025 and 11.9° (F) towards the end of century in District 7. This temperature rise is mostly uniform across the district, with possible greater temperature increases in the center of the district. These projections are for the ambient air temperature only and don't include additional heat effects, such as those from the Urban Heat Island. Los Angeles is an Urban Archipelago, where urban land covers a large area rather than covering a central point, and highest temperatures are typically found downwind.[23] Caltrans has the opportunity to consider measures that reduce the agency's impacts to Urban Heat Island through cool roofs, pavements, and landscaping, where applicable.

22 - "Extreme Weather," U.S. National Climate Assessment, accessed April 29, 2019, http://nca2014.globalchange.gov/report/our-changing-climate/extreme-weather

23 - CalEPA/Altostratus Inc., "Creating and Mapping an Urban Heat Island Index for California," April 24, 2015, https://calepa.ca.gov/wp-content/uploads/sites/62/2016/10/UrbanHeat-Report-Report.pdf.

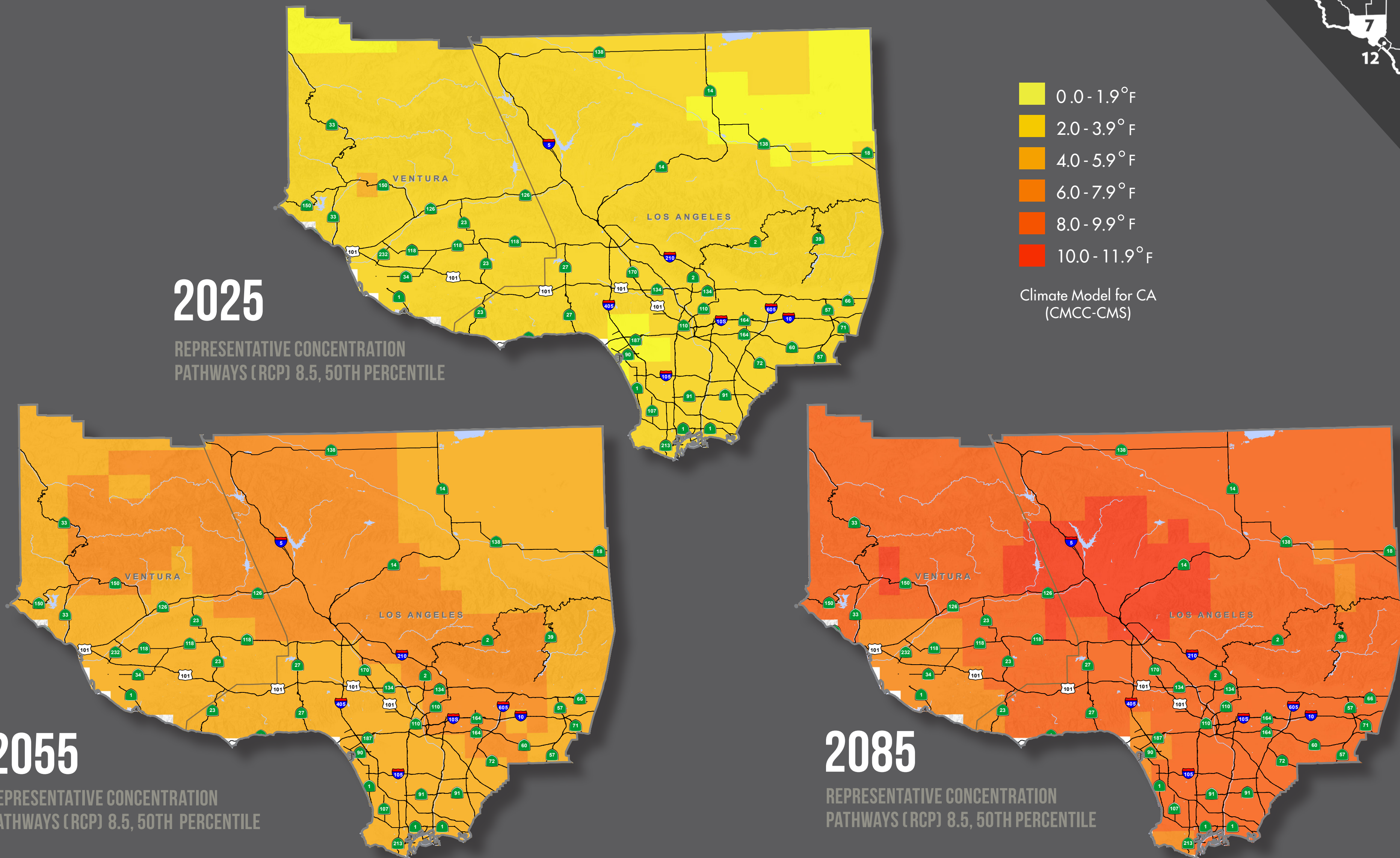
HIGH TEMPERATURES CAUSE PAVEMENT TO WEAR FASTER, AND INCREASES MAINTENANCE COSTS

ROADSIDE LANDSCAPING WILL NEED TO SURVIVE LONGER PERIODS OF HIGH TEMPERATURES

Fig. 1

CHANGE IN THE AVERAGE MAXIMUM TEMPERATURE OVER SEVEN CONSECUTIVE DAYS

A REQUIRED MEASURE FOR PAVEMENT DESIGN



Future change in the Maximum Average Temperature Over Seven Consecutive Days within District 7, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 7. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

PAVEMENT DESIGN

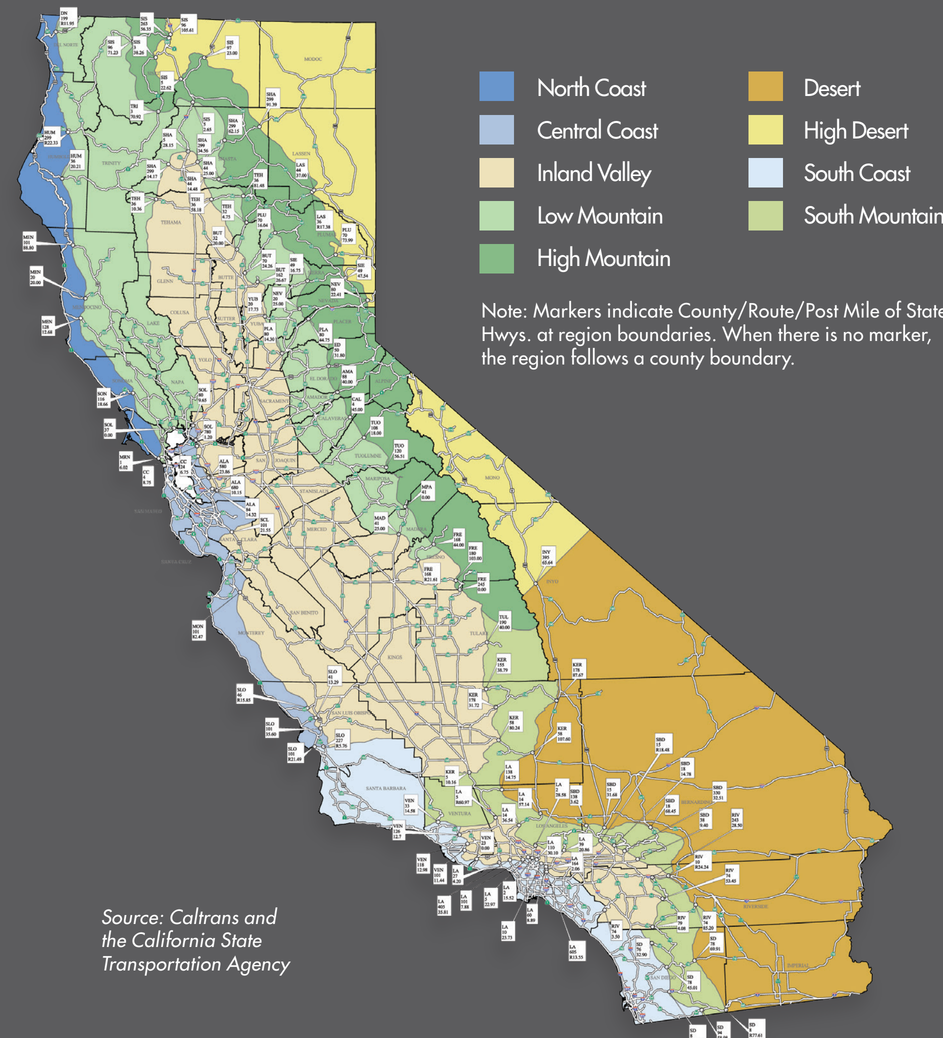
The design of pavement affects its durability and is an important component of Caltrans' highway asset management strategy. Ensuring the durability and good ride quality of highway pavements under various conditions is an important responsibility of every state transportation agency. Pavement can be either concrete or asphalt mix, depending on various factors. Selecting the pavement binder is one element of asphalt pavement design and it is an important decision based in part on temperature conditions in the project area.

Climate change preparation is different for pavement design than for other assets. Many of Caltrans' assets, including roadways, bridges, and culverts have longer design lives, so decisions made for them today need to take that into account. Asphalt pavement is replaced more frequently—approximately every 20-40 years depending on its purpose.

Caltrans has divided the state into nine pavement climate regions (as shown in Figure 2) to help determine the best pavement types for each area. Pavement design considers two main criteria: average maximum temperature over seven consecutive days, and the change in absolute minimum air temperature. This assessment's temperature projections have been formatted to fit these metrics. A primary consideration for Caltrans and its pavement design engineers will be whether the climate region boundaries could shift due to climate change, or whether climate changes across the state will alter pavement design parameters.

Fig. 2

CALTRANS PAVEMENT REGIONS



Source: Caltrans and the California State Transportation Agency

TIMEFRAMES AND ASSET DECISION-MAKING

Decision-making for transportation assets requires consideration of many factors, including how long an asset will be in place. This is often referred to as the design life, or useful life, of an asset. Some assets managed by Caltrans, like asphalt pavement, are replaced around every 20-40 years while others, like bridges, are built with the expectation of a useful life of 50 years or longer. A road alignment may be in place for a century or longer—a reality highlighted by the fact that alignment of the first national highway (as it was defined then), built to connect settlers to the Ohio Valley and the west, is still in existence today.

The two graphics included on this page highlight how design life considerations are a critical part of planning for transportation investment. Figure 3 below shows how future temperature scenarios vary widely depending on emission levels and global response. One thing to note is that the conditions are somewhat consistent through around 2050, after which they begin to diverge more significantly. This means that decisions made on investments nearing the end of century need to include a much wider range of temperature uncertainty for future conditions.

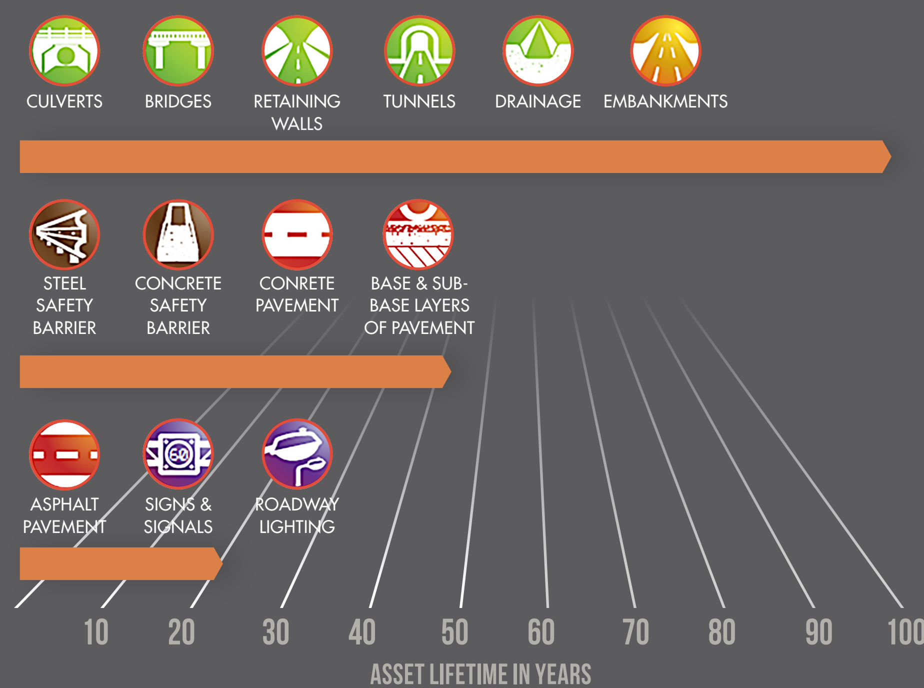
SOME ASSETS MANAGED BY CALTRANS, LIKE ASPHALT PAVEMENT, ARE REPLACED AROUND EVERY 20-40 YEARS WHILE OTHERS, LIKE BRIDGES, ARE BUILT WITH THE EXPECTATION OF A USEFUL LIFE OF 50 YEARS OR LONGER.

ASSETS WITH LIFETIMES IN THE MEDIUM RANGE, LIKE SAFETY BARRIERS, REQUIRE CONSIDERATION OF MID-RANGE FUTURE CONDITIONS.

ASSETS WITH SHORTER LIFETIMES, LIKE ASPHALT PAVEMENT, REQUIRE CONSIDERATION OF NEARER TERM FUTURE CONDITIONS.

Fig. 4

TRANSPORTATION INFRASTRUCTURE ASSETS

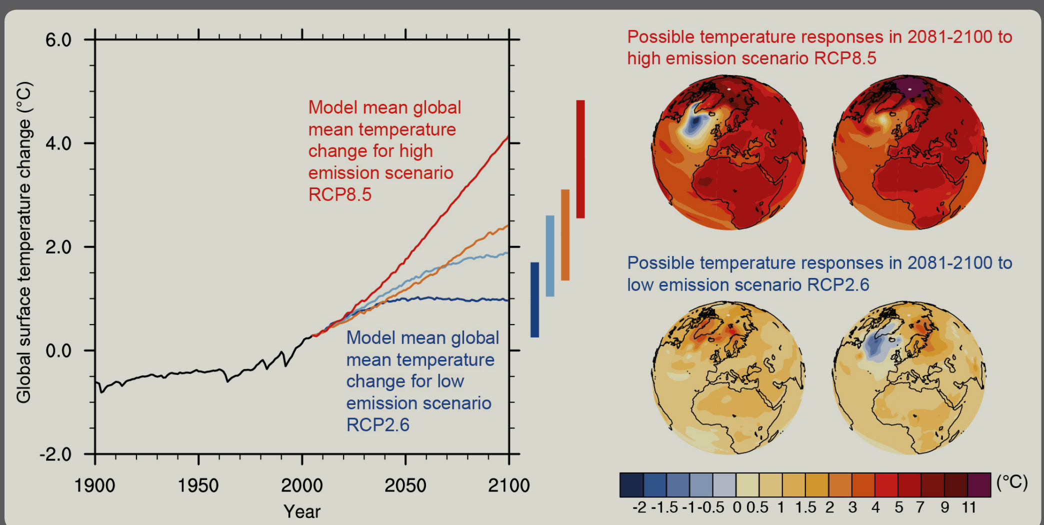


The graphic above was prepared to show how assets maintained by Caltrans will require different considerations for planning and design. All decisions should be forward-looking instead of based on historic trends, because all future scenarios show changing conditions. These future conditions must be considered when designing new transportation assets to ensure that they achieve their full design life.

Source: UK Highways Agency

Fig. 3

IPCC - CLIMATE CHANGE 2013: THE PHYSICAL SCIENCE BASIS FAQ 12.1



Source: IPCC

PRECIPITATION

Atmospheric energy and moisture increases caused by increasing temperatures are expected to change the nature of precipitation events in California. Increasingly intense storms, combined with other changes in land use and land cover, can raise the risk of damage or loss from flooding. Precipitation affects California's transportation assets in many ways, including structural damage, flooding, landslides, washouts, and erosion. A major threat to transportation assets comes not from a higher overall volume of rainfall over time, but rather from more frequent and larger storm events and their potential for damaging the State Highway System.

The University of California's Scripps Institution of Oceanography has projected future rainfall data to the year 2100 using two different GHG emission scenarios and a variety of models. A "100-year storm event" (a storm with a likelihood of occurring once every 100 years—or a one percent chance of occurring in any given year) is one useful way to examine this data. A 100-year storm could cause significant damage, so it is a good design standard for infrastructure projects. Understanding how the 100-year storm may change in the future can help Caltrans build more resilient infrastructure. See the figure on the following page for the percentage increase in the 100-year storm depth across District 7.

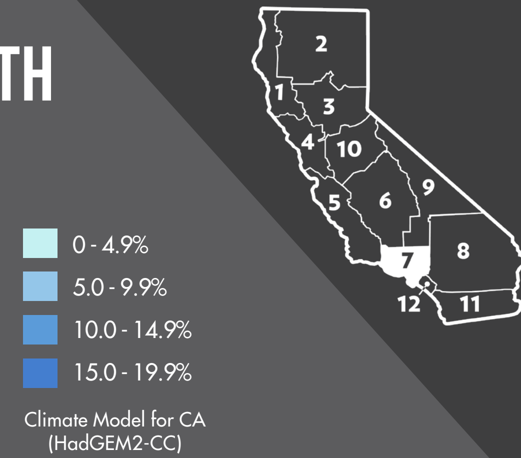
PRECIPITATION CHANGE IN DISTRICT 7

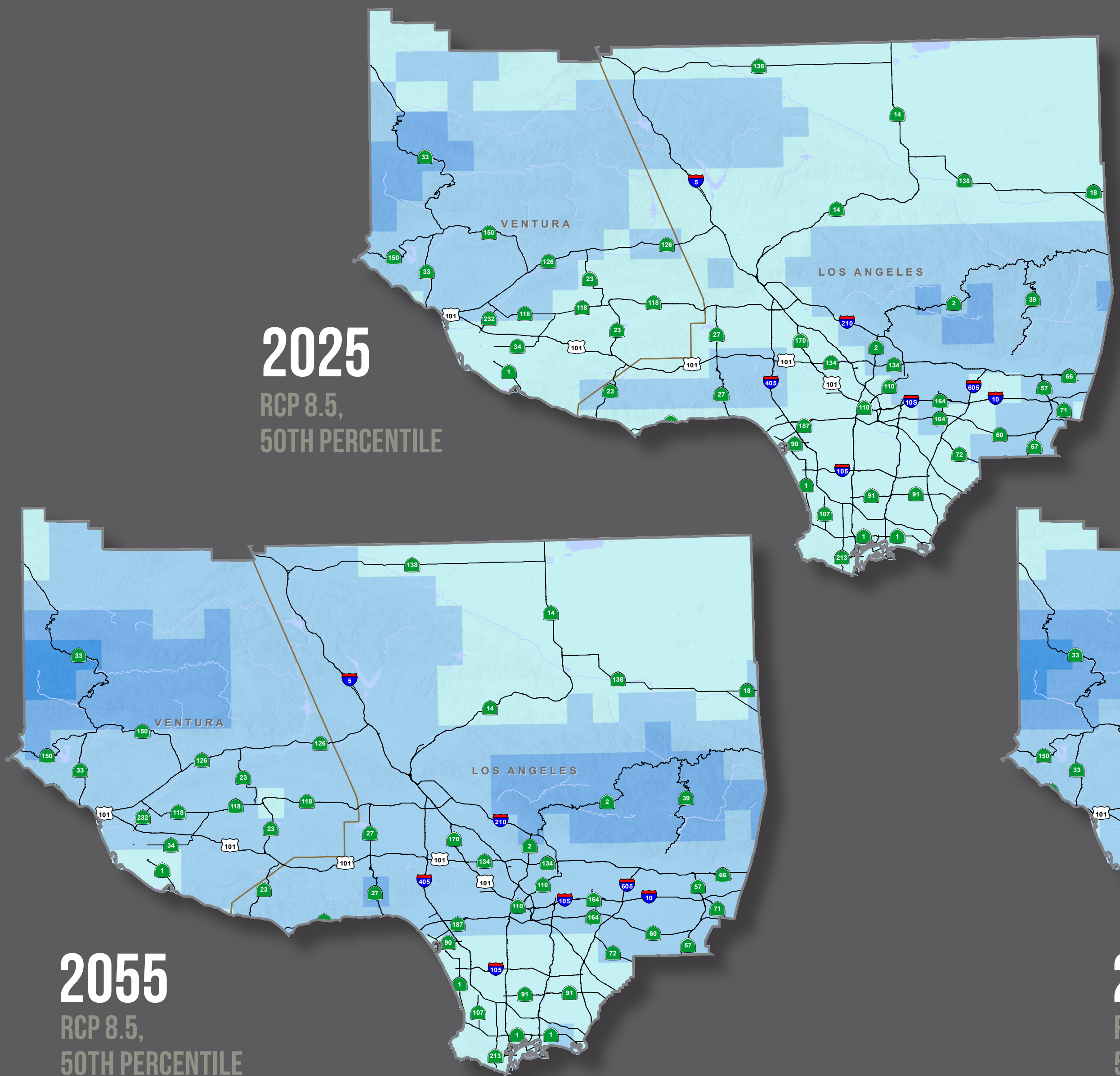
The maps of 100-year storm depth change for District 7 show the midrange of predicted precipitation increase. These projections of the 100-year storm do not account for changes to sea level rise—sea level rise and storm surge are discussed in the "Storm Surge" section. Projecting precipitation changes in California is complicated, and it is difficult to say exactly how and where rain events will occur. However, based on the available data, District 7 will have the greatest increase in 100-year storm depth in the Angeles and Los Padres National Forest regions. The expected trend is that the 100-year storm precipitation depth will increase over the coming century by anywhere from 0 to 20% in District 7.

PACIFIC COAST HIGHWAY MUDSLIDE NEAR POINT MUGU, 2014

Fig. 5

PERCENT CHANGE IN 100-YEAR STORM PRECIPITATION DEPTH





Future Percent Change in 100-year Storm Precipitation Depth within District 7, Based on the RCP 8.5 Emissions Scenario

Caltrans Transpotation Asset Vulnerability Study, District 7. Caltrans No. 74A0737. Climate data provided by the Scripps Institution of Oceanography. The data shown were generated by downscaling global climate outputs using the Localized Constructed Analogs (LOCA) technique.

WILDFIRE

RECENT WILDFIRE EVENTS IN DISTRICT 7

2017: The severity and frequency of California wildfires are expected to increase as temperatures rise and precipitation patterns change. A conservative, multimodal approach (see pages 21 & 22) projects that, compared to historical conditions, most of Ventura and Los Angeles Counties will see a 15-50% increase in cumulative area burned by fire over 30 years. Another recent study of Southern California wildfires projected that fires driven by Santa Ana winds will burn 64% more area.[24]

Already, Caltrans District 7 has responded to many devastating wildfire events. In 2017, the Thomas Fire (the second largest fire recorded in California) burned in Santa Barbara and Ventura County. It started in December and burned close to 300,000 acres, destroyed 1,063 structures, and killed two people before being contained.[25] In the aftermath, heavy rains led to mudslides that triggered evacuations, road closures, traffic accidents, and the death of 21 people.[26] The district was affected by several other major fires in December of 2017, including the Creek, Rye, and La Tuna fires. Though smaller than the Thomas Fire, these fires still had significant effects in the district and on Caltrans infrastructure:

- The Creek Fire started in December and burned 15,619 acres, destroying over 200 structures before being fully contained.[27]
- The Rye Fire also started in December, burned 6,049 acres, and destroyed nine structures.[28]
- The La Tuna Fire started in September of 2017, burned 7,194 acres and shut down the 210 Freeway.[29]

Figure 6 shows the boundaries of these fires, the Thomas Fire, and the center line miles of State Highway System within the fire perimeters.

2018: 2018 was another destructive wildfire year for Caltrans District 7 and the State of California. One of the most recent was the Woolsey Fire, which started on November 8th, 2018 and burned for 13 days. The fire killed six people, burned almost 100,000 acres, and destroyed 1,500 structures.[30] Caltrans District 7 responded by shutting down portions of US-101, State Routes 23 and 27, and the PCH. Caltrans staff also opened all four lanes of the PCH to allow better southbound evacuation. After the fire ended, District 7 undertook emergency efforts to repair damages to the State Highway System, including fixing damaged signs, guardrails, fencing, and storm drains, as well as installing erosion controls on burned slopes and removing debris.

24 Yufang Jin, Michael Goulden, Nicholas Faivre, Sander Veraverbke, Fengpeng Sun, Alex Hall, Michael Hand, Simon Hook, James Randerson, "Identification of Two Distinct Fire Regimes in Southern California: Implications for Economic Impact and Future Change, 5 Environ. Res. Lett. 10 094005, (September 2015), https://iopscience.iop.org/article/10.1088/1748-9326/10/9/094005/meta

25 "Top 20 Largest California Wildfires," CalFire, last modified March 14, 2019, https://www.fire.ca.gov/communications/downloads/fact_sheets/Top20_Acres.pdf

26 Jack Dolan, "Search Teams Find 21st Victim of Montecito Mudslide," Los Angeles Times, January 21, 2018. https://www.latimes.com/local/lanow/la-me-montecito-death-toll-20180121-story.html

27 "Creek Fire," CalFire, last modified August 6, 2018, http://cdfdata.fire.ca.gov/incidents/incidents_details_info?incident_id=1923

28 "Rye Fire," CalFire, last modified January 18, 2018, http://cdfdata.fire.ca.gov/incidents/incidents_details_info?incident_id=1924

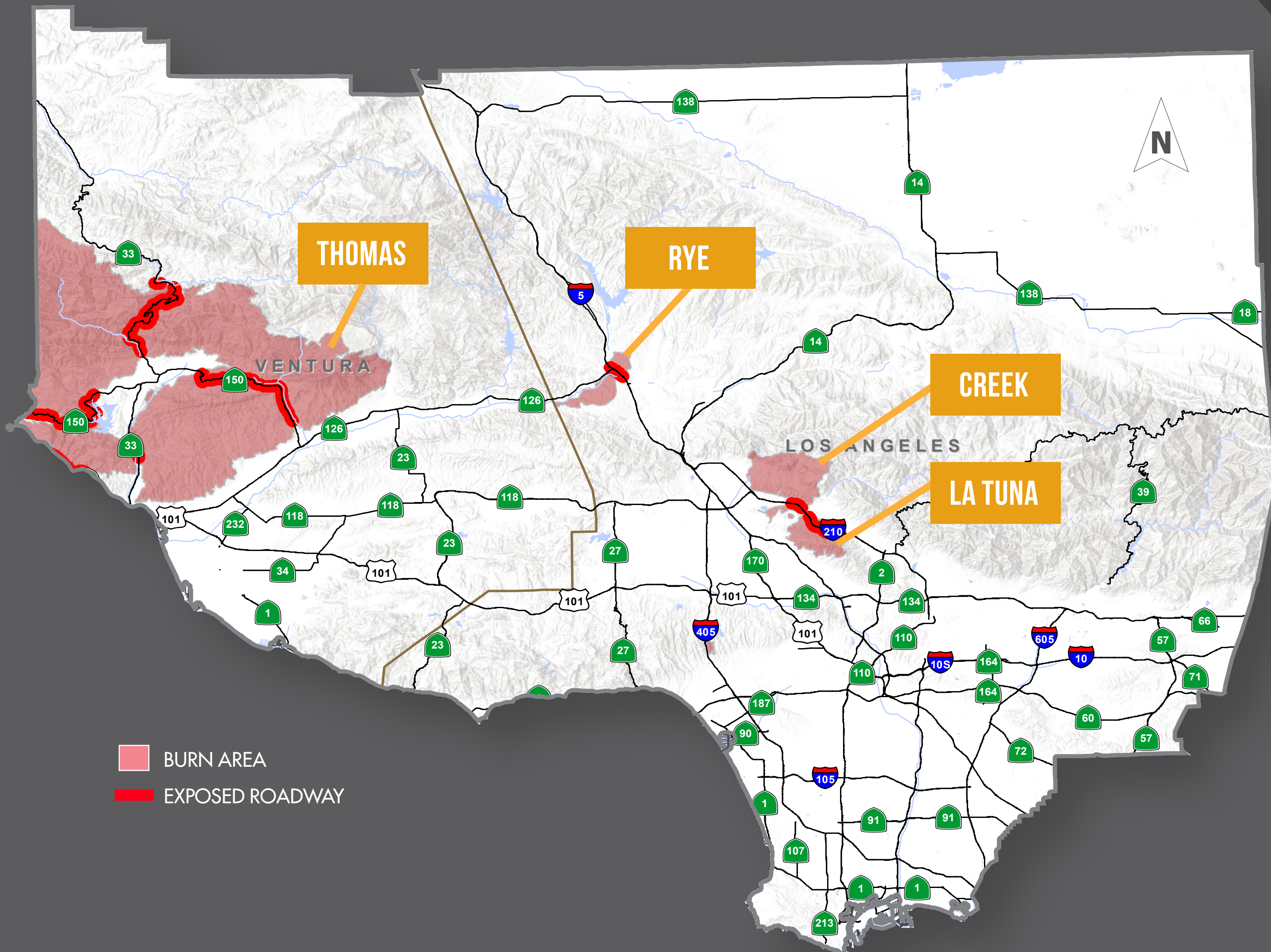
29 "La Tuna Fire," CalFire, last modified January 9, 2018, http://cdfdata.fire.ca.gov/incidents/incidents_details_info?incident_id=1800

30 "Woolsey Fire," CalFire, last modified January 4, 2018, http://cdfdata.fire.ca.gov/incidents/incidents_details_info?incident_id=2282

THOMAS FIRE, 2017

POST FIRE, US 101 IN VENTURA COUNTY, JANUARY 2016

Fig. 6



2017 Wildfires	Miles of State Highway System in Fire Perimeter
Thomas	38.8
Rye	1.5
Creek	1.0
La Tuna	3.2

WILDFIRE AND CLIMATE CHANGE

WILDFIRE PROJECTIONS FOR DISTRICT 7

Changing precipitation patterns and higher temperatures will likely influence both the intensity and scale of wildfires. Higher temperatures can lead to increased wildfire risk by decreasing the moisture in soils and vegetation—wildfires can then contribute to landslide and flooding by burning off protective land cover and reducing the capacity of the underlying soils to absorb rainfall. California is already prone to serious wildfires—the results of climate forecasts suggests that this vulnerability will get worse. To address these concerns, Governor Jerry Brown announced in May 2018 a new fund to support forest management and reduce wildfire risk. Governor Newsom later issued an Executive Order (N-05-19) to create a task force to develop a community education and resilience campaign and provide the Governor with immediate-, mid-, and long-term suggestions to prevent destructive and deadly wildfires.

Figure 7's red-shaded areas indicate an increased likelihood of wildfires based on projected percentages of area burned over time. These projections were generated using data from the MC2 – EPA (from the United States Forest Service), MC2 – Applied Climate Science Lab (University of Idaho), and the Cal-Adapt 2.0 (UC Merced) wildfire models. Individual models were paired with three downscaled global climate models to produce nine future scenarios. Starting with three different wildfire models was a conservative methodology because final data shows the highest wildfire risk categorization of all model results. RCP 8.5 (the high-emissions scenario) results are shown in Figure 7 and Table 1. See the associated Technical Report for results processed for RCP 4.5.

WILDFIRE EFFECTS IN DISTRICT 7

Large portions of District 7 are projected to be exposed to increased wildfire risk. The extent of the risk increases from the beginning to the end of the century, along with the level of risk (e.g. moderate to high),which increases over time in some areas. Most of Ventura County is vulnerable to increased wildfire risk. In Los Angeles County, the risk is limited primarily to the Angeles National Forest area. There is no projected wildfire concern for large urban areas such as the City of Los Angeles and Oxnard where the land cover is not prone to fire—the same is true for desert areas in northern Los Angeles County. For a summary of the District 7 State Highway System center line miles exposed to wildfire risk over time, see Table 1.

Table 1: Miles of Roadways in Medium to Very High Wildfire Exposure Areas, Under the High Emissions Scenario

County	Miles		
	2025	2055	2085
Ventura	152.7	155.6	157.6
Los Angeles	297.2	303.3	311.6

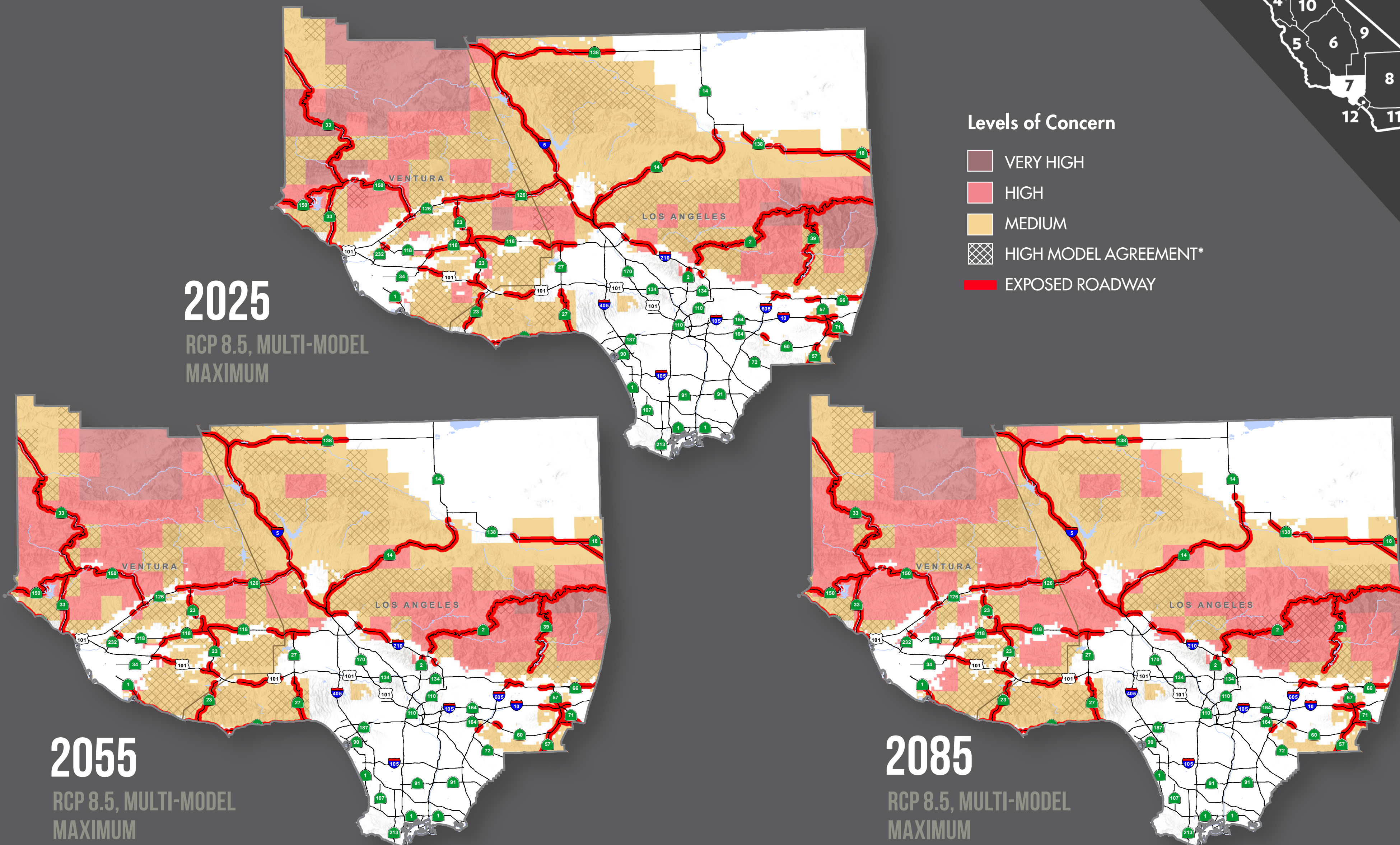
PINE FIRE, US 101 IN VENTURA COUNTY
JANUARY 2016

SOLIMAR FIRE WHICH CLOSED THE US-101 AND PCH | DECEMBER 2015

PACIFIC COAST HIGHWAY | WOOLSEY FIRE, 2018

Fig. 7

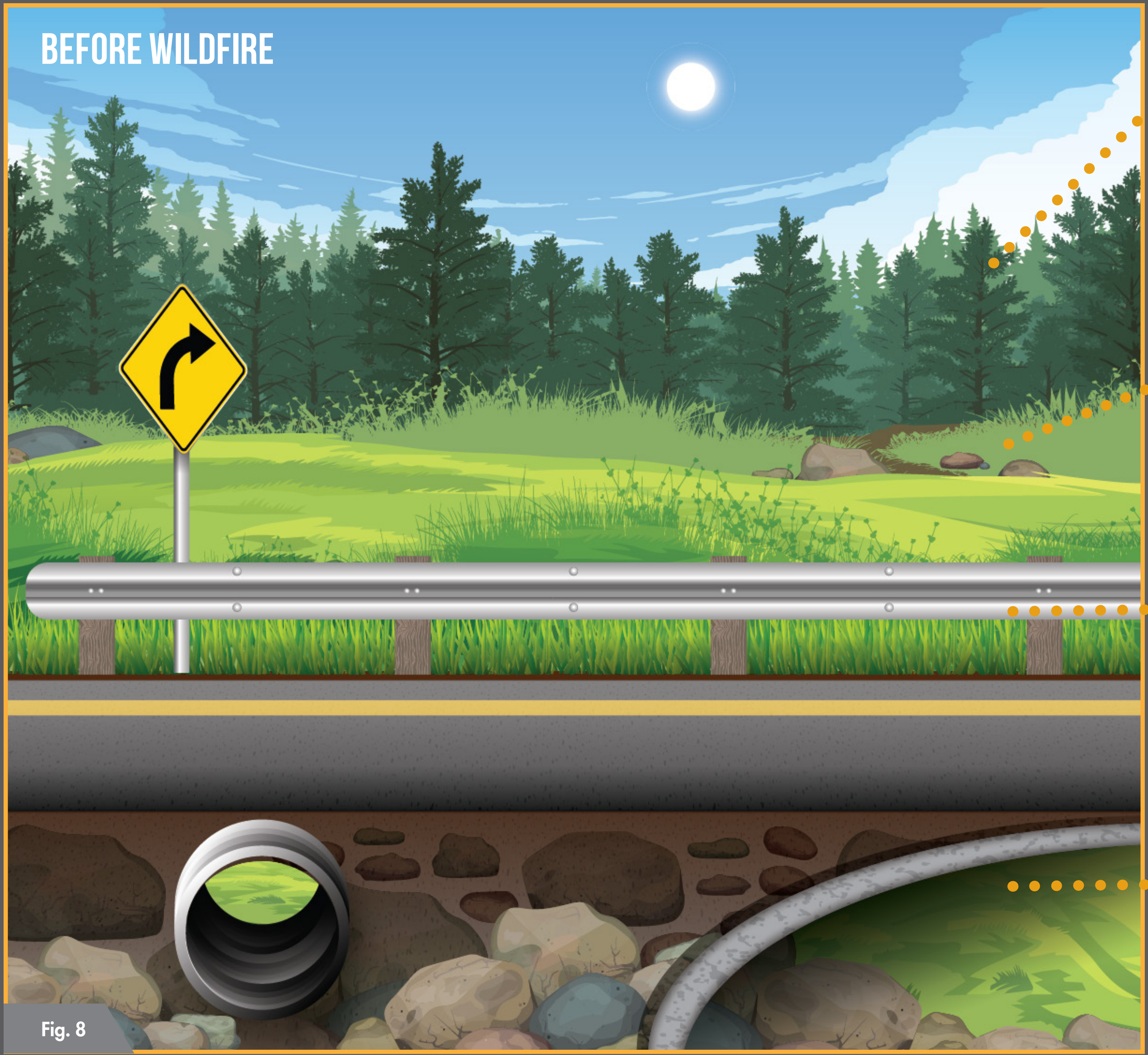
LEVEL OF WILDFIRE CONCERN



Future level of Wildfire Concern for the Caltrans State Highway System within District 7, Based on the RCP 8.5 Emissions Scenario.

The fire model composite summaries shown are based on wildfire projections from three models: (1) MC2 - EPA Climate Impacts Risk Assessment, developed by John Kim, USFS; (2) MC2 - Applied Climate Science Lab at the University of Idaho, developed by Dominque Bachelet, University of Idaho; and (3) University of California Merced model, developed by Leroy Westerling, University of California Merced. For each of these wildfire models, climate inputs were used from three GCMs: (1) CAN ESM2; (2) HAD-GEM2-ES; and (3) MIROC5. The maps show the multi-model maxima for each grid cell across the nine combinations of the three fire models and the three GCMs.

* The hashing shows areas where 5 or more of the 9 models fall under the same cumulative % burn classification as the one shown on the map.



FOREST/TREE COVER MODERATES RAINFALL EFFECTS ON THE GROUND, LIMITING EROSION OF THE SOILS

GROUNDCOVER OF TREES, SHRUBS AND GRASSES STABILIZE AND SLOW SURFACE FLOWS AND FACILITATE RAINFALL INFILTRATION INTO THE SOIL

INSTALLED SIGNS AND GUARDRAILS IMPROVE SAFETY FOR ROADWAY USERS

CLEAR CULVERTS ALLOW WATER TO PASS UNDER THE ROADWAY AND PROVIDE WILDLIFE CROSSINGS

Healthy vegetated areas provide various ecosystem services contributing to precipitation infiltration and soil stabilization. These natural systems help prevent potential damage to roadways, bridges, and culverts by mitigating excessive flood water and preventing erosion.

LOSS OF FOREST COVER RESULTS IN MORE EROSION OF SOILS

BURNED SOILS ARE UNABLE TO FACILITATE THE INFILTRATION OF RAINFALL, INCREASING RUNOFF

LOSS OF STABILIZING GROUNDCOVER RESULTS IN LOOSER SOILS AND INCREASED LANDSLIDE POTENTIAL

BURNED GROUND COVER LEADS TO MORE DEBRIS THAT CAN CLOG CULVERTS/BRIDGES DURING RAINFALL EVENTS

DESTROYED SIGNS AND GUARDRAILS REDUCE DRIVER SAFETY

DAMAGED OR CLOGGED CULVERTS INCREASE RISK OF ROAD OVERWASHING, DAMAGE, AND ELIMINATES OPTIONS FOR WILDLIFE CROSSING

Fig. 9

After wildfires have occurred, new risks are posed to transportation assets in the area. Immediately after a fire, the loss of signs and guardrails presents a danger to travelers and require an immediate response. Other impacts noted in the graphic above can exist as a potential risk to Caltrans assets for years after a wildfire event occurs.

SEA LEVEL RISE

Sea level rise represents a long-term threat to coastal areas like District 7, which covers an extensive coastline. Sea level rise will exacerbate the flooding and inundation that already occur across the district during regular storm or tidal events. District 7 is especially concerned about the PCH on the South Coast of Ventura County and US-101 on the North Coast, as they are vulnerable to flooding under current conditions. In Ventura County's sea level rise vulnerability assessment study, the county identified that with 5 feet (1.50 meters) of sea level rise and a 100-year storm, approximately 45 miles of county roadway would be vulnerable to flooding, including highways maintained and operated by Caltrans.[31]

Like other forecasted changes in climate, the projected timing of sea level rise varies, depending in part on the assumptions made regarding future concentrations of GHGs and how the Earth's systems will respond. The State of California Sea Level Rise Guidance: 2018 Update provides the most recently developed sea level rise projections for locations across the California coastline[32] and direction on how to use them in decision-making. Figure 11 shows some examples.

The projections were used and paired with sea level rise heights modeled by the Coastal Storm Modeling System (CoSMoS). The United States Geological Survey (USGS) developed CoSMoS to model the potential inundation from sea level rise and storm surge using sea level heights ranging from 1.64 feet (0.50 meters) to 16.40 feet (5.00 meters). The data was developed to model sea level rise and storm surge beyond the average daily high tide for most of the California coast and within the San Francisco Bay. The District 7 analysis also includes cliff retreat data created by the CoSMoS model for portions of Southern California.

The assessments of sea level rise, surge, and cliff retreat on the following pages include bridges that may also be subject to sea level rise, but not necessarily overtopping, because the rise alone can pose risks. Figure 12 illustrates some of these risks to bridges from sea level rise. Bridges are included as exposed areas on the maps provided and their mileage is included in Tables 2, 3, and 4.

SEA LEVEL RISE EFFECTS IN DISTRICT 7

Rather than showing district-scale maps of potential sea level rise impacts, this report highlights a few specific areas in District 7 that are vulnerable to sea level rise, storm surge, and cliff retreat. The Port of Los Angeles was chosen to demonstrate how rising seas can affect multiple District 7 highways. The image to the right shows that Route 47, Interstate 710, and the PCH all merge at the Port and are exposed to future sea level rise. The red sections are exposed to 1.64 feet (0.50 meters) of sea level rise, orange sections are exposed to 3.28 feet (1.00 meters), and yellow sections are not exposed until 5.74 feet (1.75 meters) of rise. It is important to note that some of the red sections (exposed to 1.64 feet) may be bridges or elevated roadways. However, these areas could become exposed to increased scour or erosion, and future analysis could still be necessary. Connections to the Port are significant for movement of goods and it will be essential for District 7 to mitigate this risk to these highways.

See Table 2 for a summary of center line miles of the District 7 State Highway System that are exposed to various heights of sea level rise. For full district-scale maps of sea level rise, see the associated District 7 Technical Report.

31 - County of Ventura: Resource Management Agency – Planning Division, "VC Resilient Coastal Adaptation Project: Vulnerability Assessment Report," December 14, 2018, https://vcrma.org/vc-resilient-coastal-adaptation-project

32 - California Ocean Protection Council, State of California Sea-Level Rise Guidance: 2018 Update, March 14, 2018, http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf

Table 2: Miles of District 7 State Highway System Exposed to Sea Level Rise Inundation

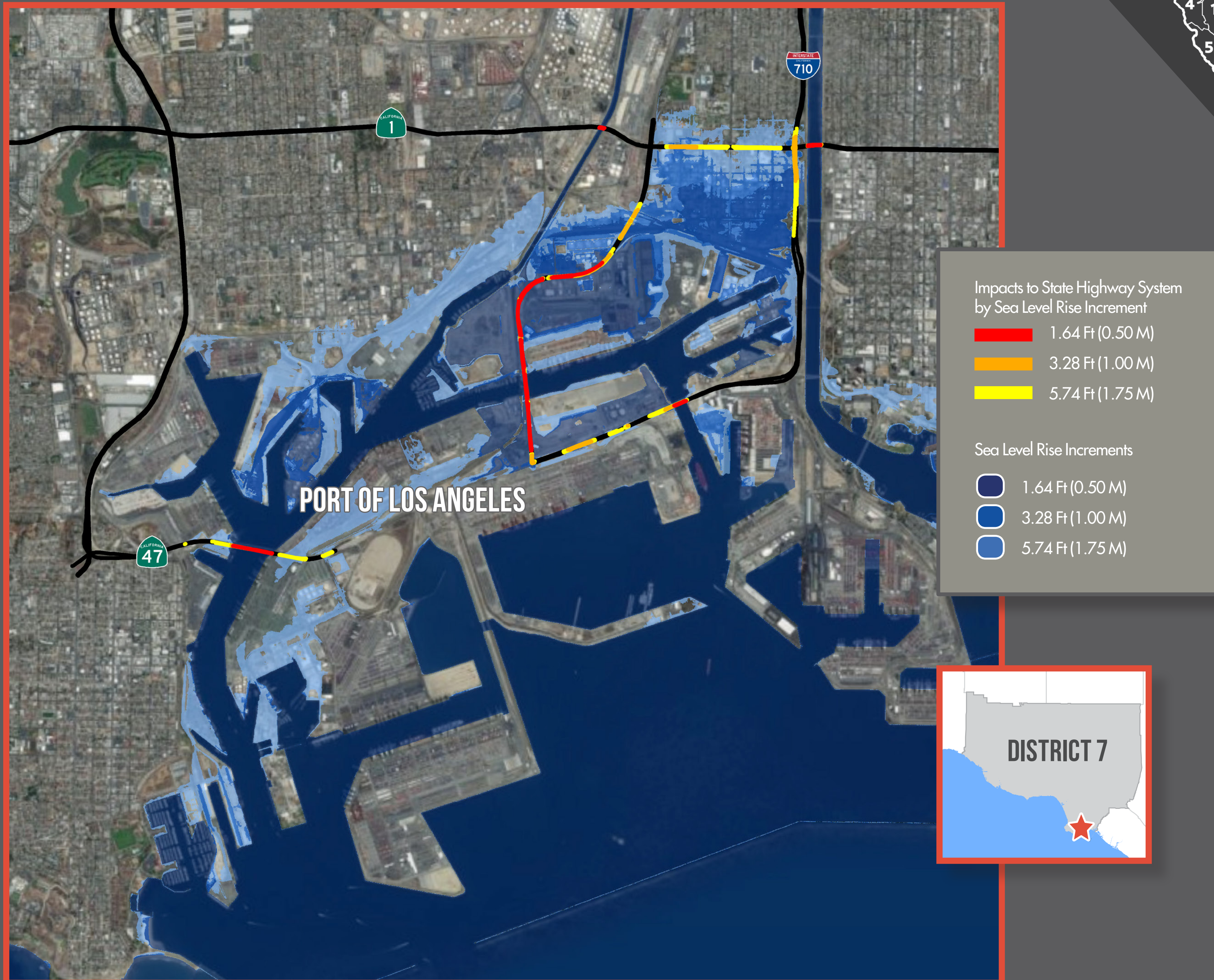
County	Miles		
	1.64 ft (.5 m)	3.28 ft (1 m)	5.74 ft (1.75 m)
Ventura	0.20	0.21	2.39
Los Angeles	2.61	4.03	6.91

ANALYSIS FOR THIS REPORT WAS CONDUCTED ON THREE DISTINCT INCREMENTS OF SEA LEVEL RISE TO SHOW HOW CONDITIONS MAY CHANGE OVER TIME. THOSE INCREMENTS INCLUDED 1.64 FEET (.5 METERS), 3.28 FEET (1 METER) AND 5.74 FEET (1.75 METERS)

APPROXIMATELY NINE MILES OF CALTRANS DISTRICT 7 STATE HIGHWAYS MAY BE EXPOSED TO SEA LEVEL RISE UNDER 5.74 FEET OF SEA LEVEL RISE.

Fig. 10

SEA LEVEL RISE INUNDATION



Sea level rise data are from the US Geological Survey, Coastal Storm Modeling System (CoSMoS). See Our Coast, Our Future and the USGS CoSMoS webpage for more information on the model.

Fig.11

SEA LEVEL RISE ESTIMATED FOR DISTRICT 7

Estimates of sea level rise have been developed for California by various agencies and research institutions. The graph on the right reflects estimates recently developed for Los Angeles by a scientific panel for the 2018 Update of the State of California Sea-Level Rise Guidance, an effort led by the Ocean Protection Council (OPC).[33] These projections were developed for gauges along the California coast based on global and local factors that drive sea level rise such as thermal expansion of ocean water, glacial ice melt, and the expected amount of vertical land movement.

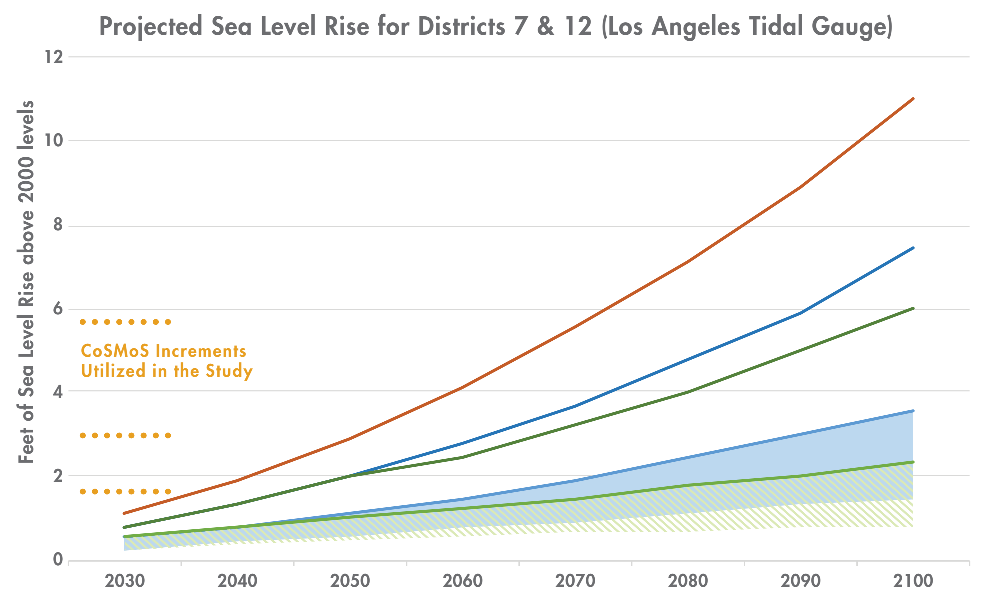
Sea level rise projection scenarios presented in the OPC guidance identify several values or ranges, including:

- A median (50%) probability scenario
- A likely (66%) probability scenario
- A 1-in-20 (5%) probability scenario
- A low (0.5%) probability scenario
- An extreme (H++) scenario to be considered when planning for critical or highly vulnerable assets with a long lifespan

Each of these values are presented for low (RCP 2.6) and high (RCP 8.5) emissions scenarios to provide information on the full range of potential projections over time. The OPC recommends using only RCP 8.5 for projects that have a lifespan to 2050, and using both scenarios for projects with longer lifespans. The OPC also recommends assessing a range of future projections before making decisions on projects, given the uncertainty inherent in modeling inputs. Guidance is provided for when best to consider certain projections, given the risks associated with projects of varying type:

- **For low risk aversion decisions**, the OPC recommends using the likely (66%) probability sea level rise range. In the graphic to the right, this range is shaded in light blue for the RCP 8.5 scenario and is shaded in light green for RCP 2.6.
- **For medium to high risk aversion decisions**, the OPC recommends using the low (0.5%) probability scenario. This value is shown in dark green for RCP 2.6 and in dark blue for RCP 8.5 in the graphic to the right.
- **For high risk aversion decisions**, the OPC recommends considering the extreme (H++) scenario. This projection is shown in dark orange in the graphic to the right.

This guidance was developed by the OPC to help state and local governments understand future risks associated with sea level rise and incorporate these projections into work efforts, investment decisions, and policy mechanisms. The OPC recognizes that the science surrounding sea level rise projections is still improving and anticipates updating their guidance at least every five years. Given that new findings are inevitable, Caltrans will use best-available sea level rise modeling, projections, and guidance as the science evolves over time, and will be working in the coming months to define how this data is incorporated into capital investment decisions.



Note: RCP 2.6 values for 2030-2050 are linearly interpolated from the 2000 baseline, with interpolated values constrained to maximum of their equivalent RCP 8.5 values.

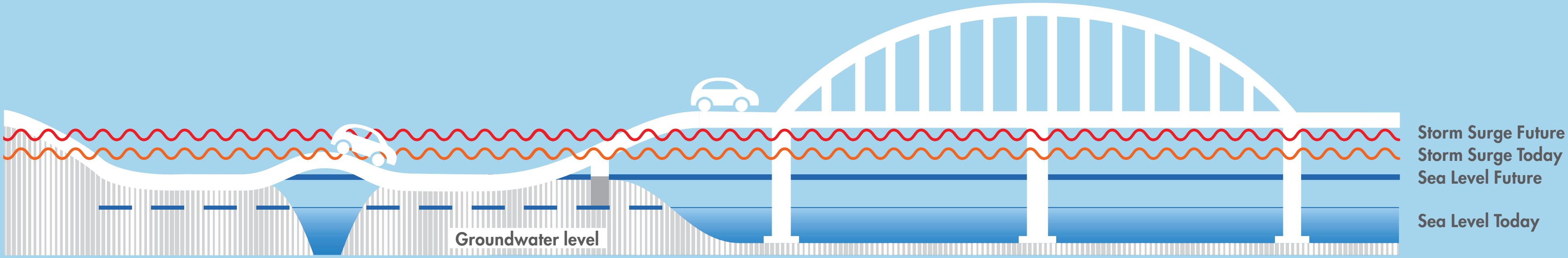
OPC Estimates for Sea Level Rise

- Extreme Estimate of Sea Level Rise (H++ Scenario)
- **Low Probability** Estimate (0.5% Probability Scenario) for **High Emissions** Scenario
- **Low Probability** Estimate (0.5% Probability Scenario) for **Low Emissions** Scenario
- **High End of the Likely Range** (17% Probability Scenario) for **High Emissions** Scenario
- **Likely Range** (66% Probability Range) for **High Emissions** Scenario
- **High End of the Likely Range** (17% Probability Scenario) for **Low Emissions** Scenario
- **Likely Range** (66% Probability Range) for **Low Emissions** Scenario

33 - California Ocean Protection Council, State of California Sea-Level Rise Guidance: 2018 Update, March 14, 2018, http://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20180314/Item3_Exhibit-A_OPC_SLR_Guidance-rd3.pdf

Fig. 12

BRIDGES IN COASTAL AREAS AND CLIMATE CHANGE



Climate change can impact infrastructure in multiple ways. Bridges in coastal areas, for example, can be directly impacted by rising sea levels and storm surge effects. Today's bridges were designed and built for current tidal and surge conditions, so increasing water levels may increase the risk for these facilities in the future.

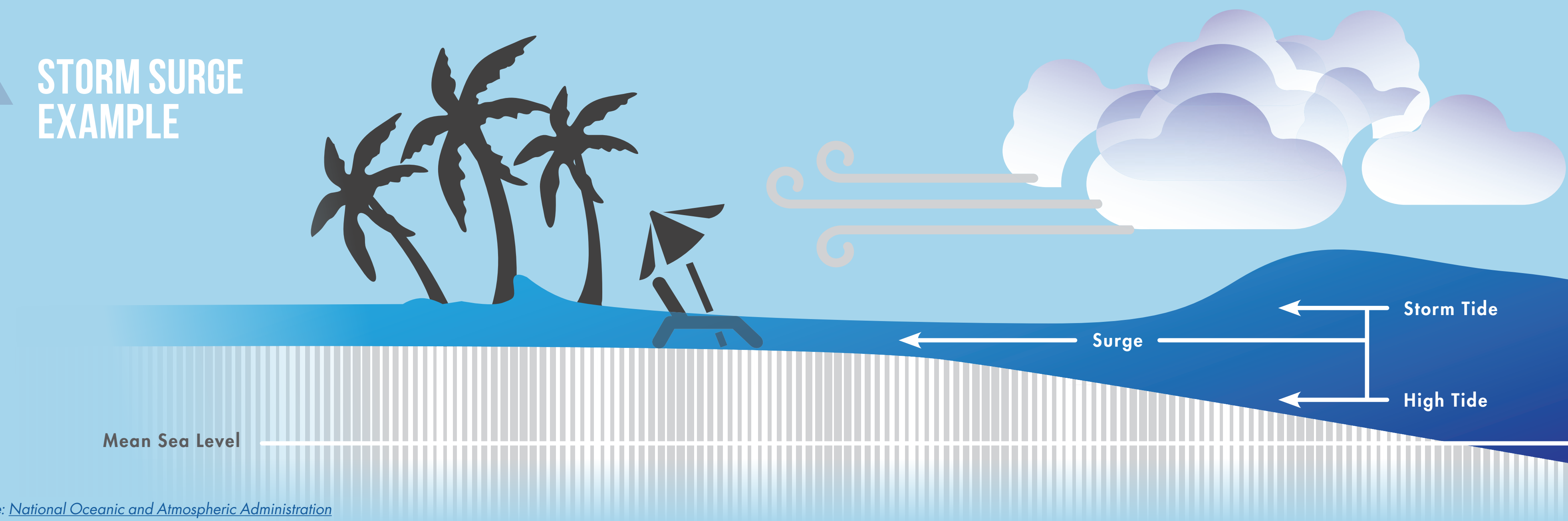
Some of bridge vulnerabilities include:

1. Rising groundwater table inundating supports that were not built for saturated soil conditions, leading to erosion of soils and loss of stability.
2. Higher sea levels exerting greater forces on the bridge during normal tidal processes, increasing scour effects on bridge structure elements.
3. Higher water levels causing higher, more forceful, storm surges which could cause scour on bridge substructure elements.
4. Bridge approaches (where the roadway transitions to the bridge deck) becoming exposed to surge forces and sustaining damage from storms.
5. Surge and wave effects loosening or damaging portions of the bridge and requiring securing, re-attaching, or replacing of bridge parts.
6. Bridge use becoming limited due to the loss or damage of a roadway or minor bridges near the bridge approaches.

Most bridges are built with added safety factors during design so these concerns may not be realized—but they should be factored into decision-making to ensure that all Caltrans bridges can withstand conditions that will change over time.

Fig. 13

STORM SURGE EXAMPLE



Source: National Oceanic and Atmospheric Administration

STORM SURGE

The threat to coastal areas from sea level rise is an even greater concern when combined with storm surge. Storm surge will expose coastal infrastructure to even higher forces, which will likely further increase damage and reduce its useful life. District 7 is especially concerned about the portions of the State Highway System that are already flooding under current conditions and will be subject to more severe and frequent flooding in the future. There are already 19 miles of roadway in Ventura County alone that are vulnerable to a 100-year storm event, including portions of the PCH and US-101.[34]

As with the sea level rise portion of this analysis, CoSMoS data was used to assess sea level rise and storm surge impacts to the State Highway System in District 7. The model provides outputs for a variety of storm events, including an annual storm, a 20-year storm, a 100-year storm, and a King Tide. The results from the 100-year storm analysis and three sea level rise heights are reported here.

Figure 14 shows the sections of the State Highway System in the Los Angeles area of District 7 at high risk of flooding due to sea level rise and storm surge from a 100-year storm. These state highways are critically important for local communities and intrastate travel and commerce. Temporary flooding would lead to delays and resulting effects to the surrounding community, as well as direct impacts on highway infrastructure.

34 - County of Ventura: Resource Management Agency – Planning Division, "VC Resilient Coastal Adaptation Project: Vulnerability Assessment Report," December 14, 2018, https://vcrma.org/vc-resilient-coastal-adaptation-project

STORM SURGE EFFECTS IN DISTRICT 7

As seas rise, more water is in motion during storm events. These higher water levels can cause higher wave run up and more forceful storm surge conditions, which will increase long-term risks to infrastructure. Figure 13 identifies the basic elements of storm surge and how it is different from normal tidal conditions. The graphic, supplied by the National Oceanic and Atmospheric Administration (NOAA) and edited for this study, shows how water levels increase and reach farther inland during storm events and how that compares to a regular high tide.

Table 3 reflects the total miles of the State Highway System inundated in District 7 under a 100-year storm event and different heights of sea level rise. Storm surge adds approximately 8 miles of flooding to the State Highway System under 5.74 feet (1.75 meters) of sea level rise, compared to sea level rise alone (Table 2). As seas keep rising, coastal storms could cause more frequent and widespread flooding of coastal highways. Figure 14 shows a selection of the State Highway System in District 7 north of Point Mugu State Park that could be exposed to temporary flooding from a 100-year storm event. The associated District 7 Technical Report includes mapping of all exposed areas in District 7.

Table 3: Miles of District 7 State Highway System Exposed to Surge During a 100-Year Storm

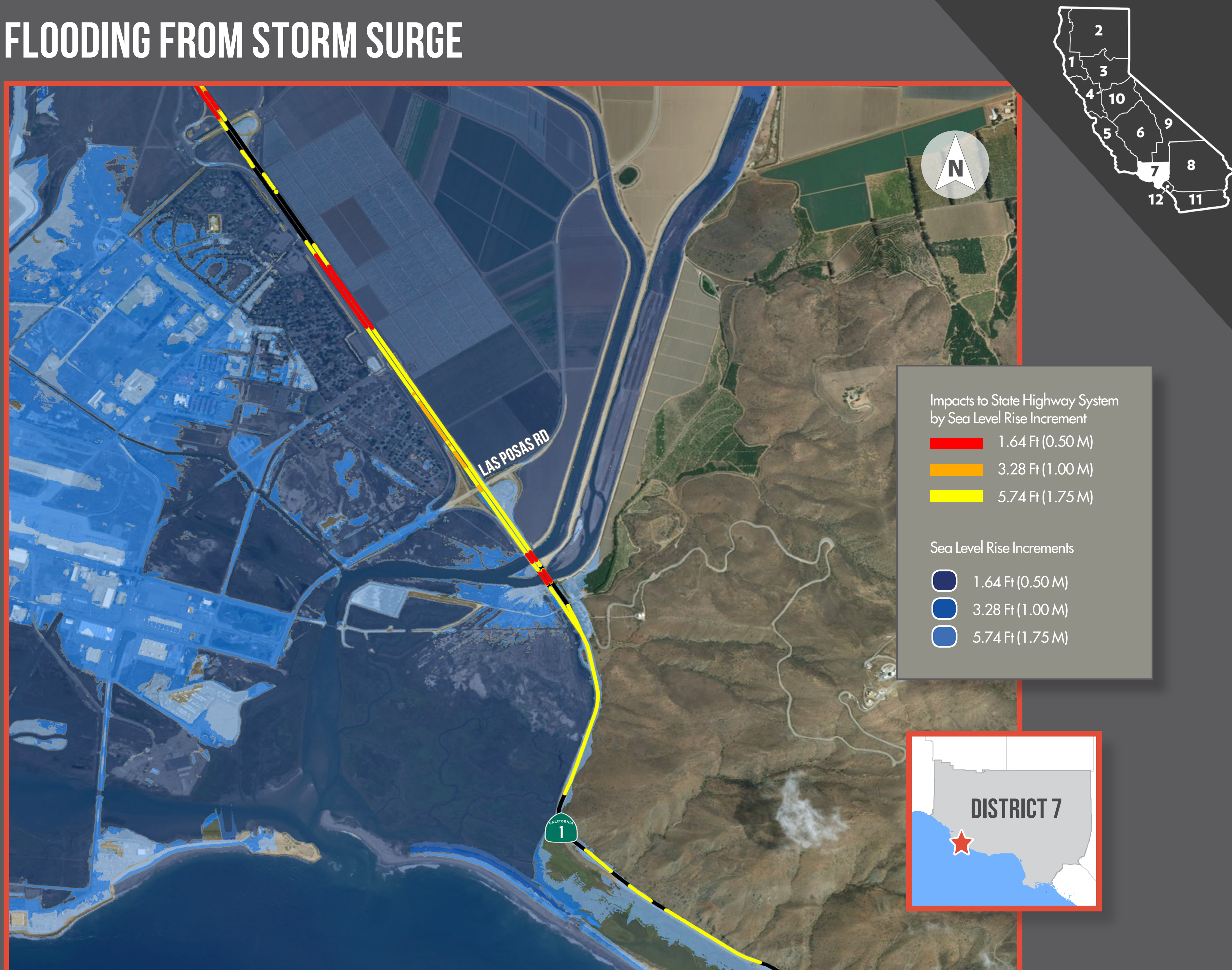
County	Miles		
	1.64 ft (.5 m)	3.28 ft (1 m)	5.74 ft (1.75 m)
Ventura	1.94	2.82	8.82
Los Angeles	3.72	5.83	8.36

ABOUT 17 MILES OF ROADWAYS AND BRIDGES IN DISTRICT 7 COULD BE EXPOSED TO THE 100-YEAR STORM AND 5.74 FEET OF SEA LEVEL RISE

REPAIRED FAILED PCH SUPPORT SLOPES DAMAGED DUE TO STORM SURGES AND HIGH SURF.

Fig. 14

FLOODING FROM STORM SURGE



Sea level rise and surge (100-year storm) data are from the US Geological Survey, Coastal Storm Modeling System (CoSMoS). See Our Coast, Our Future and the USGS CoSMoS webpage for more information on the model.

CLIFF RETREAT

Changing sea levels will also create different forces at the shoreline by eroding beaches and causing cliff retreat along the 1,100-mile California coastline. Cliff retreat occurs when waves impact the base of a cliff, and hydraulic action carves out some of the cliff face. As the loss of rock and soil increases, it undermines support for the cliff itself, until eventually, the cliff face collapses. Over time the cliff recedes, or "retreats," from its original position. District 7 is concerned about the impacts this will have on coastal highways in the district, such as parts of the PCH and US-101. Ventura County estimates that erosion due to sea level rise and storm surge could damage 14 miles of county roads.[35]

Rates of cliff retreat will depend on several factors, including the rate of sea rise, the physical makeup of the cliffs, and the effectiveness of adaptation responses by state agencies and other stakeholders. The best strategies to address long-term concerns will likely consider the trade-offs between, 1) engineered and natural infrastructure solutions to protect the coastline, and 2) physical relocation of infrastructure and communities away from eroding areas.

As with the sea level rise and surge analyses, the USGS CoSMoS model was applied for a District 7 analysis of cliff retreat to help determine the long-term coastal changes from sea level rise. The CoSMoS model's cliff retreat data is only available for Southern California (extending from Point Conception in Santa Barbara County to Imperial Beach in San Diego County). The model provides cliff retreat data with two different assumptions—one which assumes that coastal armoring will be 100% effective at preventing cliff retreat ("hold the line"), and one which assumes that coastal armoring is ineffective, and cliff retreat continues past current protections ("do not hold the line").[36] For this analysis, the "do not hold the line" scenario was applied to assess the full potential of cliff retreat impacts in District 7. Figure 15 shows these projections of cliff retreat for one portion of the PCH in District 7.

CLIFF RETREAT EFFECTS IN DISTRICT 7

The mapped area shows exposure on the PCH near Point Mugu State Park, where the highway runs along the coastline on a cliff side. Portions of this stretch of highway are expected to be exposed to cliff retreat impacts under just 1.64 feet (0.50 meters) of sea level rise. See Table 4 for a summary of District 7 State Highway System center line miles are exposed to cliff retreat impacts at the mapped sea level rise heights. Full district-scale maps of cliff retreat are available in the associated District 7 Technical Report.

35 - County of Ventura: Resource Management Agency – Planning Division, "VC Resilient Coastal Adaptation Project: Vulnerability Assessment Report," December 14, 2018, https://vcrma.org/vc-resilient-coastal-adaptation-project

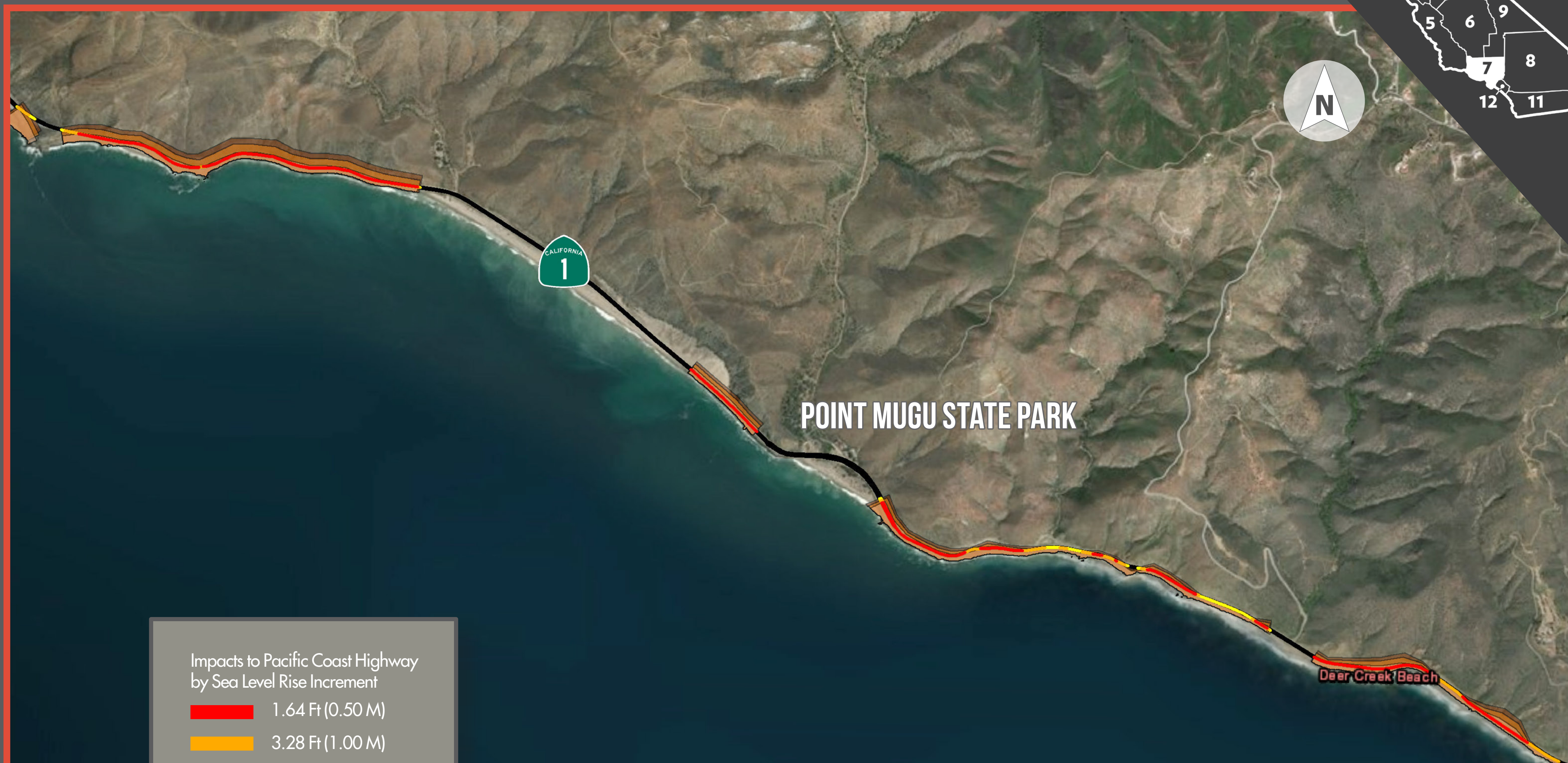
36 - "CoSMoS Southern California v3.0 Phase 2 projections of coastal cliff retreat due to 21st century sea-level rise metadata," USGS, last modified August 14, 2018, https://cmgds.marine.usgs.gov/catalog/pcmsc/cosmos/CoSMoS_v3Ph2_CoastalCliff_projections_metadata.faq.html

Table 4: Miles of District 7 State Highway System Exposed to Cliff Retreat

County	Miles		
	1.64 ft (.5 m)	3.28 ft (1m)	5.74 ft (1.75 m)
Ventura	3.00	3.75	4.24
Los Angeles	1.38	1.57	1.63

Fig. 15

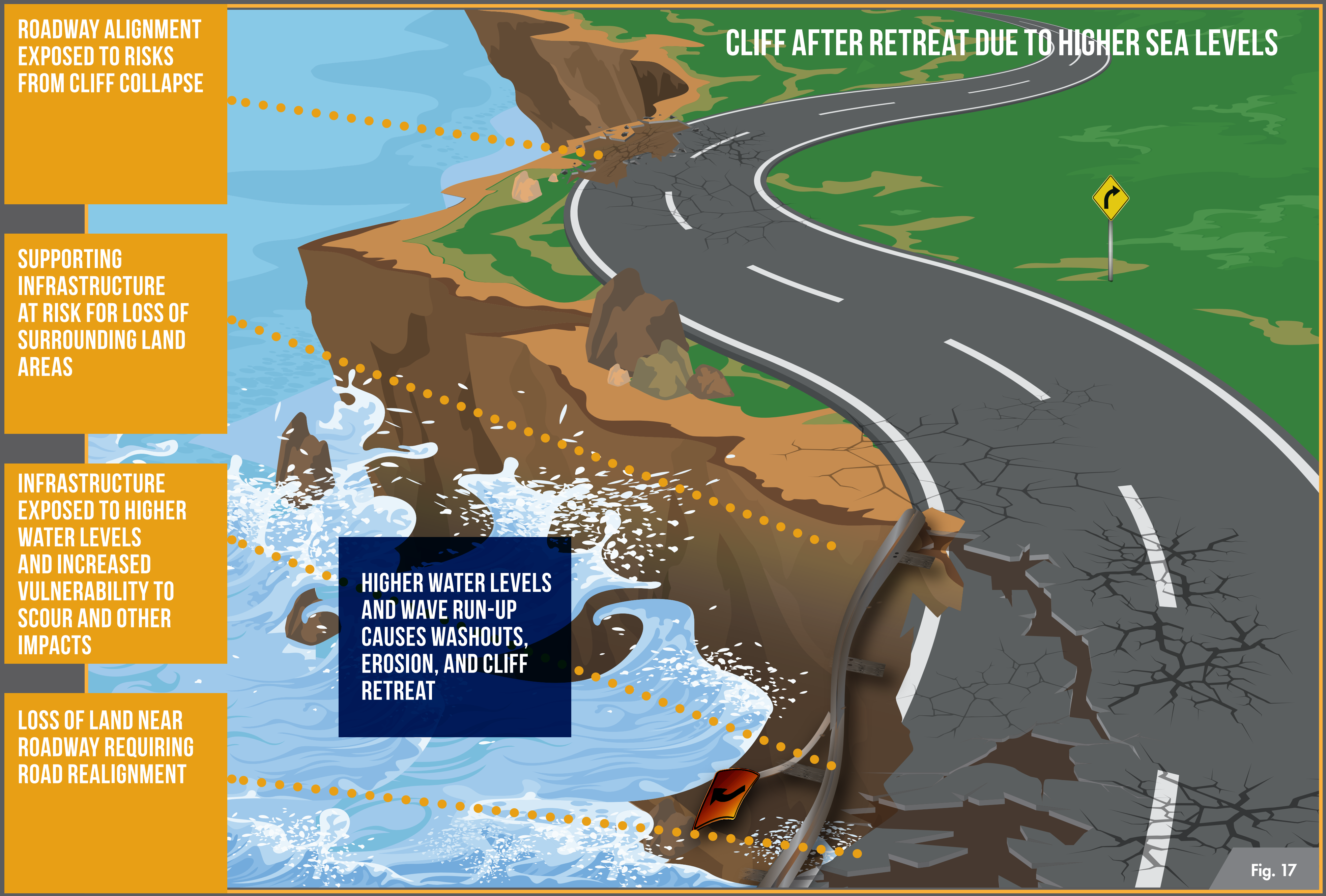
CLIFF RETREAT



Cliff retreat data are from the US Geological Survey, Coastal Storm Modeling System (CoSMoS). This data applies the "do not hold the line" management option, which assumes that cliff retreat continues unimpeded. See Our Coast, Our Future and the USGS CoSMoS webpage for more information on the model. See the CoSMoS v3.0 Summary of Methods for more information on cliff retreat modeling for Southern California.

Fig. 16

The California coastline has been shaped in part by forces from ocean water and waves from past storm events.



Future conditions with higher water levels associated with sea level rise will extend flooding and inundation inland and impart more forces on the California coastline, resulting in cliff retreat.

INFRASTRUCTURE IMPACT EXAMPLE

As climate changes, California will be affected by more frequent, extreme weather events. In recent years, California has been through a severe drought (2012 – 2016), a series of extreme storm events that caused flash flooding and landslides across the state (2017 – 2018), the worst wildfire season on record (2017), and deadly mudslides in Southern California (2018). These emergencies demonstrate what could become more commonplace for California in the future, as droughts, storm events, and wildfires become more frequent and severe. It is important to learn from these events, take actions to prevent them wherever possible, and increase the resiliency of transportation infrastructure for near- and long-term threats. This section provides an example of a weather-related event at the district level and the district response.

TRANCAS CREEK BRIDGE REPLACEMENT

The PCH has been recently damaged by landslides and wave run-up in multiple locations in District 7. In this example, the damage occurred to Trancas Creek Bridge, which crosses Trancas Canyon south of Thousand Oaks. In August of 2017 the bridge was scoured by a heavy rain event which caused the bridge footings to be exposed.

Following a bridge inspection, the Trancas Creek Bridge was found to be scour-critical and vulnerable to a 10-year storm event. By working in collaboration with the CCC and the City of Malibu, District 7 proposed to replace the bridge with a wider one to better accommodate traffic, bicyclists, and pedestrians, and mitigate future scour to abutments. The preferred alternative is longer than the existing bridge to improve fish passage and adapt to stronger creek flows associated with storm events and a future restoration of Trancas Lagoon. The preferred alternative would include an ADA-approved path connecting the beach with Trancas Lagoon, which is scheduled for restoration by the Santa Monica Mountains Resource Conservation District and the National Park Service.

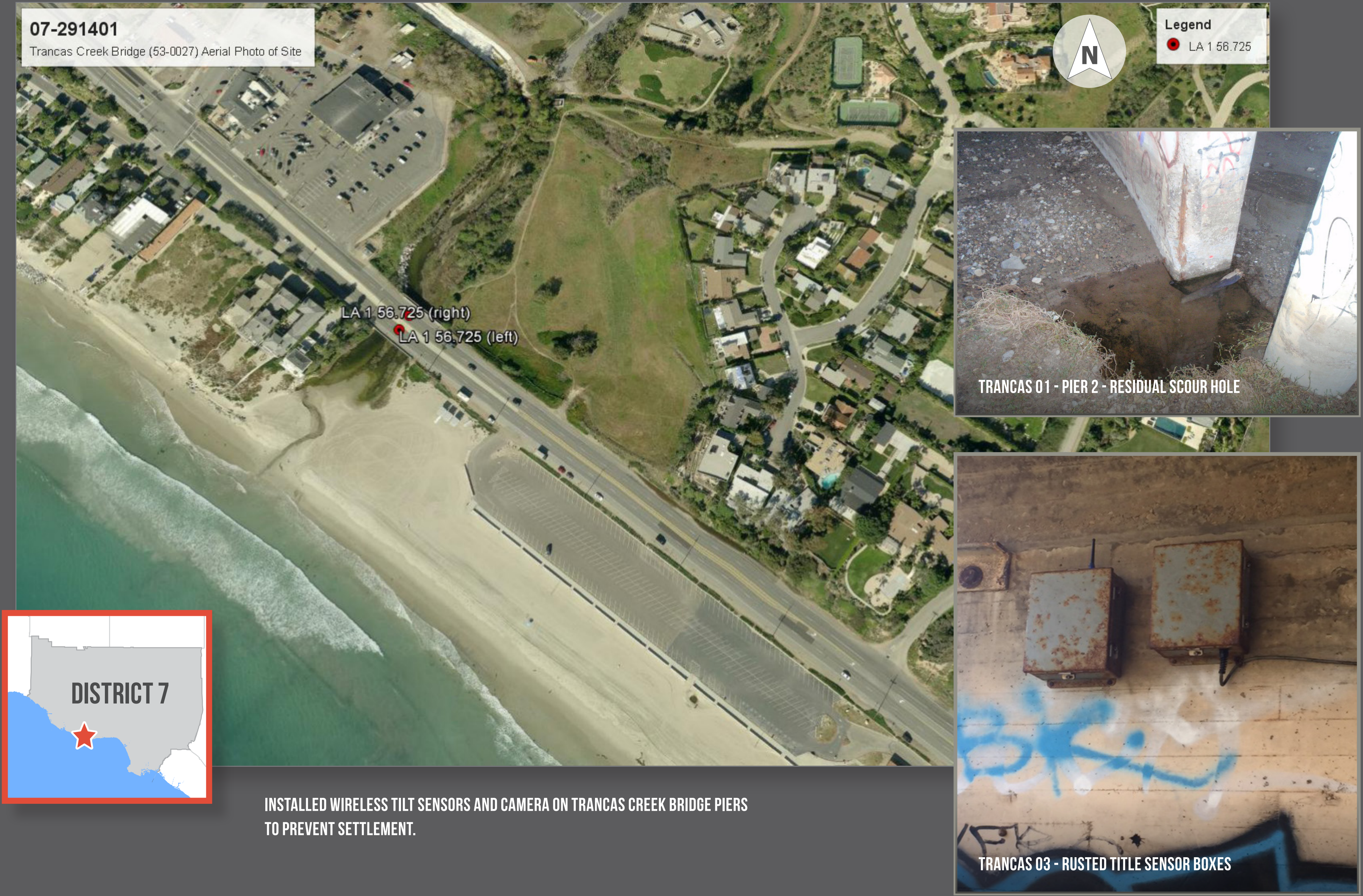
Caltrans has considered the potential effects of tides and sea level rise on the new structure, and plans to complete a wave run-up study during the next stages of project development. As Caltrans moves forward with building new shoreline structures and rehabilitating older ones, it will continue to address the effects of future sea level rise and storm surge on each project.

For more information on the Trancas Creek Bridge replacement, visit: http://www.dot.ca.gov/d7/projects/trancas/

THE CURRENT DAMAGE TO SCOUR-CRITICAL TRANCAS CREEK BRIDGE ON THE PACIFIC COAST HIGHWAY

Fig. 18

TRANCAS CREEK BRIDGE REPLACEMENT PROJECT SITE



TRANCAS 01 - PIER 2 - RESIDUAL SCOUR HOLE

TRANCAS 03 - RUSTED TITLE SENSOR BOXES

INSTALLED WIRELESS TILT SENSORS AND CAMERA ON TRANCAS CREEK BRIDGE PIERS TO PREVENT SETTLEMENT.

ADAPTIVE DESIGN, RESPONSE, AND RISK MANAGEMENT

Many areas of District 7 experienced flood damage or extended periods of road closure due to recent heavy rainfall. Maintenance and design responses to similar events in the future should consider this report's findings that future extreme precipitation events will likely contain more rainfall, and thus this, coupled with impacts from sea level rise, will increase flood damage potential. The median climate model for California predicted increases in 100-year storm precipitation depths of up to 19% for parts of District 7 under RCP 8.5. Addressing damage by rebuilding to previous designs may not be the most appropriate strategy.

Risk-based design strategies are one way of developing an effective adaptation response to climate stressors and dealing with the uncertainties of future climate conditions. A risk-based decision approach considers the broader implications of damage and loss in determining the design approach. The Federal Highway Administration has developed a framework for making design decisions that incorporate climate change: The Adaptation Decision-Making Assessment Process (ADAP)[37] process.

At its core, the ADAP process is a risk-based, scenario-driven design process. It incorporates broader economic and social costs, as well as projected future climate conditions, into design decision-making. It can be considered a type of sensitivity test for Caltrans assets and it incorporates an understanding of the implications of failure on Caltrans system users, and the agency's repair costs. The ADAP flowchart shows the basic elements of what could be included in the assessment of flooding for existing roads in District 7. The same procedures could be used in planning and designing future projects so that climate change is appropriately considered.

37 - Adaptation Decision-Making Assessment Process," FHWA, last modified January 12, 2018, https://www.fhwa.dot.gov/environment/ sustainability/resilience/ongoing_and_current_research/teacr/adap/index.cfm

LAS TUNAS BEACH WAVE RUN-UP STUDY

Between 2014 - 2016, Caltrans implemented the Las Tunas Beach Rehabilitation Project. The project's goal was to repair and expand a rock slope protection revetment along the oceanfront roadway embankment between the PCH and Las Tunas State Beach (PM 41.8/42.1). As a part of project planning, the California Coastal Commission included a wave run-up study as a requirement to obtain the Coastal Development Permit for this project.

Using best engineering practices, Caltrans analyzed beach and coastal characteristics near the project site as part of the wave run-up study. The technical study determined the sea level rise effects, wave transformation, wave run-up on coastal structures, design water level, short and long-term beach evolution, potential tsunami impacts, and coastal structure susceptibility. Sea level rise projections were assessed out to the year 2100, which ranged between 1.38 and 5.48 feet. Wave run-up was calculated on top of these sea level rise projections, bringing final water levels to 29.96 to 32.33 feet for the year 2100.

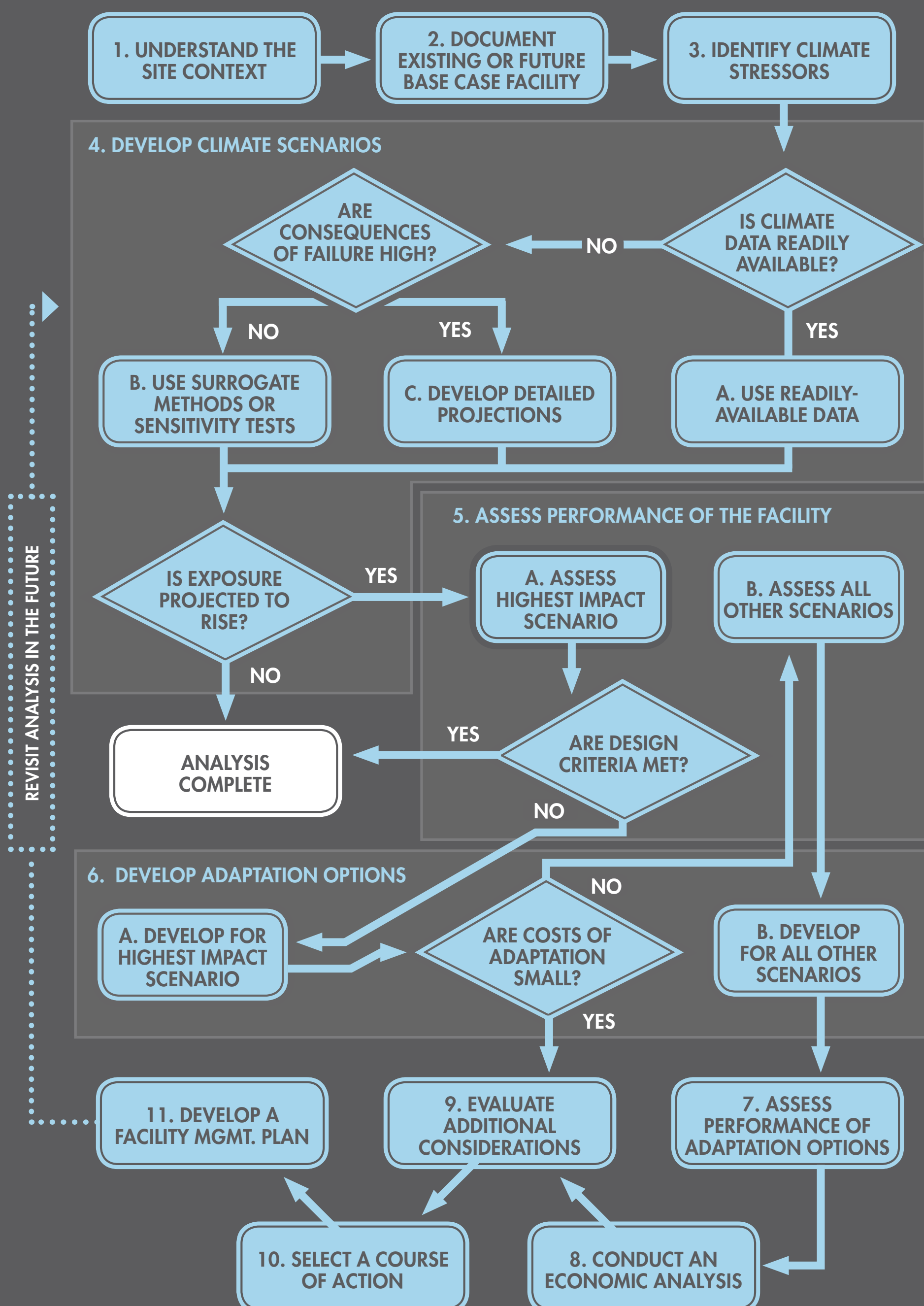
Other alternatives to continued use of rock slope protection were considered for this location, such as soldier pile and retaining walls, drilled shafts, micropiles, and a viaduct. However, the PCH and embankment lie within the Las Tunas/Le Grande Bulge Landslide, and any structural alternatives would require mitigation of the slide, use of extremely deep foundations, and work outside the state right-of-way. These alternatives were rejected as infeasible.

While rock slope protection and coastal hardening strategies like these are a typical approach to mitigating wave run-up and coastal erosion, Caltrans also hopes to implement natural infrastructure solutions moving forward. This is due, in part, to Caltrans' responsibility to provide mitigation for any beach loss that occurs when placing rip-rap or other structures. With the continued help and guidance of the Coastal Commission, Caltrans hopes to aid in maintaining existing Coastal Act resources like sandy beaches, public access and recreation areas.

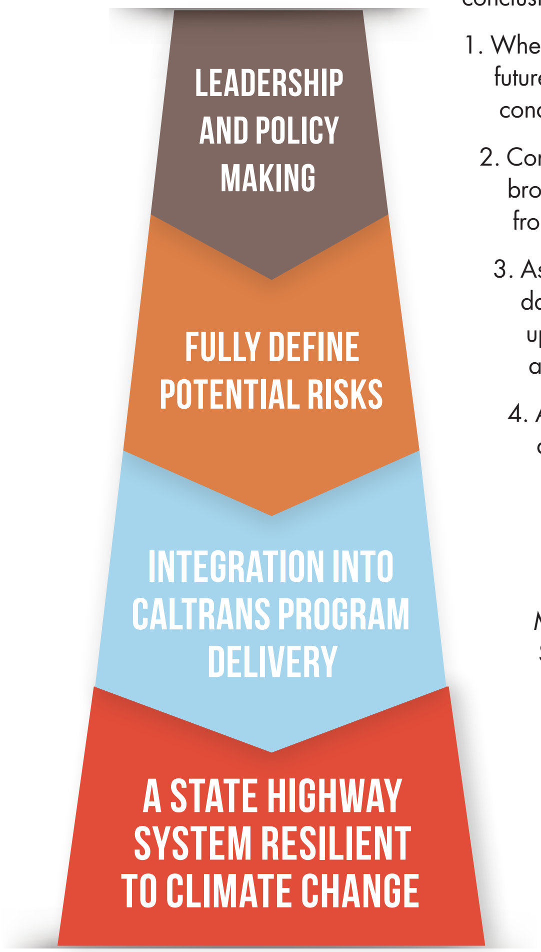
BEFORE AND AFTER PHOTOS OF LAS TUNAS BEACH, LOOKING SOUTHBOUND

Fig. 19

FHWA'S ADAP DESIGN PROCESS



EXPANDED ROCK SLOPE PROTECTION WAS ADDED TO LAS TUNAS BEACH TO PROTECT THE PACIFIC COAST HIGHWAY AGAINST WAVE RUN-UP



WHAT DOES THIS MEAN TO CALTRANS?

GENERAL CONCLUSIONS

District 7's recent extreme weather events provide an opportunity to address several of the potential climate change impacts outlined in this report. Caltrans can draw the following conclusions:

1. When building or repairing District 7 facilities, consider future conditions as opposed to relying on historical conditions (page 4 – state policies)
2. Consequence costs should factor into redesign to assess broader economic measures and the potential cost savings from adaptation (page 8 – vulnerability approach)
3. As a part of event reponse, include best available climate data from state resource agencies when developing updated design approaches (page 11 – phases for achieving resiliency)
4. Apply FHWA's ADAP process when planning or designing facilities and assets. This will help account for uncertainties in climate data and provide a benefit-cost assessment methodology that considers long-term costs to guide decisions (page 37 – Adaptive Design, Response, and Risk Management)

Many climate stressors threaten the State Highway System, as outlined in this report. Effective risk management will require a response that prioritizes the system's most vulnerable and critical assets. Addressing these concerns will also require:

FULLY DEFINING RISKS

This report does not offer a full accounting of risks from changing climate conditions. The ADAP process will be required to identify specific risks from the full range of potential impacts at an asset-by-asset level. To fully assess and address risks, evaluate assets outside of normal Caltrans control (but which could affect state highway operation if they failed, such as dams and levees).

INTEGRATION INTO CALTRANS PROGRAM DELIVERY

Caltrans programs (including policies, planning, design, operations, and maintenance) should be redesigned to consider long-term climate risks. They should also consider uncertainties inherent in climate data by adopting a climate scenario-based decision-making process based on the full range of climate predictions. Caltrans is now evaluating internal processes to understand how to best incorporate climate change into decision-making.

LEADERSHIP

Leadership at the state government and transportation agency levels will be required. The broader economic implications of transportation system damage, failure, or loss are often not adequately considered, causing them to be undervalued—so avoiding the possible impacts of extreme weather events and climate change on the State Highway System should be policy and capital programming priorities.

COMMUNICATION AND COLLABORATION

Adapting to climate change challenges will require a collaborative and proactive approach. Caltrans recognizes that stakeholder input and coordination are necessary to develop analyses and adaptation strategies that support and build upon the state's current body of work. Collaboration with other state agencies and local communities on adaptation strategies can lead to better decisions and a collective, stronger response.

A STATE HIGHWAY SYSTEM RESILIENT TO CLIMATE CHANGE

Systematically and comprehensively considering climate change (using this report as a guide for the first steps) will lead to a State Highway System that is more resilient to extreme events and climate change.

ON-LINE MAPPING TOOL FOR DECISION-MAKING

Caltrans has created an online mapping program to provide information for users across the state, using data assembled for this project. The Caltrans Climate Change Vulnerability Assessment Map can be accessed here.[38]

This tool enables Caltrans staff, policy-makers, residents and others to identify areas along the State Highway System where vulnerabilities may exist, or how temperature and precipitation may change over time.

The map viewer will be dynamic, incorporating new data as it is developed from various projects undertaken by Caltrans and will be maintained to serve as a resource for all users. The tool will be updated with data for each district as vulnerability assessments are developed.

Complex geospatial analyses were required to develop an understanding of Caltrans assets exposed to sea level rise, storm surge, cliff retreat, temperature, and wildfire. The general approach for each stressor's geospatial analysis went as follows:

- **Obtain/conduct stressor mapping:** The first step in each GIS analysis was to obtain or create maps showing the presence and value of a given climate stressor at various future time periods.
- **Determine critical thresholds:** To highlight areas affected by climate change, the geospatial analyses for certain stressors defined the critical thresholds for which the value of a hazard would be a concern to Caltrans.
- **Overlay the stressor layers with Caltrans State Highway System to determine exposure:** Once high hazard areas had been mapped, the next step was to overlay the Caltrans State Highway System centerlines with the data to identify the segments of roadway exposed.
- **Summarize the miles of roadway affected:** The final step in the geospatial analyses involved running the segments of roadway exposed to a stressor through Caltrans' linear referencing system, which provides an output GIS file indicating the centerline miles of roadway affected by a given hazard.

Upon completion of the geospatial analyses, GIS data for each step was saved to a database that was supplied to Caltrans. This GIS data will be valuable for future Caltrans efforts and is provided on the Caltrans online map viewer shown here.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